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REVISED

TEXT-BOOK OF GEOLOGY

BY

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"CORALS AND CORAL ISLANDS," REPORTS OF WILKES'
EXPLORING EXPEDITION, ON GEOLOGY, ZOÖPHYTES,
AND CRUSTACEA, ETC.

FIFTH EDITION, REVISED AND ENLARGED

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PREFACE.

The late Professor Dana had begun a revision of this work a short time before his death. The request of his family that I should complete the work of my revered teacher, was responded to with something like a feeling of filial obligation.

It was proposed in the plan of revision that the distinctive characteristics of the book should be preserved so far as possible. It was to be brought down to the present time as regards its facts, but it was still to express the well-known opinions of its author. The general plan of arrangement was to be kept unchanged, and the size of the book to be increased as little as possible.

In the progress of the work it became manifest that the usefulness of the book would be increased by certain changes more radical than had been at first contemplated. The zoölogical and botanical classifications used in the former edition were judged to be obsolete. The endeavor has been made to substitute for them, as nearly as practicable, the classifications which are followed in the majority of recent manuals on zoölogy and botany, whether precisely accordant with my own views or not. It was decided that the theory of evolution required fuller recognition than it had received in the previous edition of this work or the last edition of the Manual. It was a proof of Professor Dana's remarkable hospitality to new ideas, that he adopted a belief in evolution at an age when most men are incapable of important changes of opinion. But the idea of evolution never influenced his thinking in general as it doubtless would have done had he embraced it earlier. In the present edition, the bearing of various events in geological history upon the theory of evolution is pointed out in the appropriate places; and, in the closing chapter, which has been entirely rewritten, the general bearing of paleontology upon evolution is discussed. The treatment of metamorphism also was believed to require considerable modification, especially with reference to dynamic metamorphism and the development of a foliated structure in igneous rocks.

With these exceptions, the book presents substantially the views of the science which were held by the author in his later years, and which are embodied in that monumental work, the fourth edition of the Manual. I have been the more willing to follow this course, since in the main my own opinions are in harmony with those of my teacher; although on a few points, if the responsibility for the book had been solely my own, the views expressed would have been somewhat different, as, for instance, in regard to the geographic and climatic oscillations of the Quaternary era. It is a delicate task, in revising the work of another, to discriminate between errors which should be corrected, and statements at variance with the editor's opinions, which, in deference to the author, should be left unchanged. I cannot flatter myself that questions of this sort have always been decided aright. I have doubtless sometimes changed too much, and sometimes too little.

The only important change in the arrangement of the book, the insertion of the chapter on Zoölogical and Botanical Classification before the chapter on Dynamical Geology, was indicated in the notes left by the author. The practice followed by Professor Dana, in previous editions of this book, and in his other works, of writing the names of zoölogical and botanical groups with anglicized terminations, has been followed, in general, in this edition. The full Latin form of names of groups above the grade of family has been used only in cases where no anglicized form is sanctioned by general usage. Professor Dana's plan of terminating names of rocks in *yte*, in distinction from the names of minerals which terminate in *ite*, it has been deemed best to abandon, as that innovation in nomenclature has not been adopted by other writers.

The appendix to the former edition, giving localities of fossils, has been omitted. It is believed that such a list is not of much value unless given in more detail than the space at disposal would permit. Teachers who desire such a list are referred to Schuchert's *Directions for Collecting and Preparing Fossils*, published as Part K of Bulletin No. 39 of the United States National Museum.

I take this opportunity for grateful acknowledgments to Professor E. S. Dana, Ph.D., for his appreciative sympathy in the perplexities of my work; to the publishers, for their earnest coöperation in the endeavor to make the book as good as possible; to G. K. Gilbert, A.M., of the

United States Geological Survey, for valuable criticisms on the manuscript; and to my son, Professor E. L. Rice, Ph.D., for assistance in the correction of the proof. It is hoped that the book in its revised form will prove itself adapted to the use of students in our schools and colleges, and that it will keep before their minds the name and the scientific work of one of the greatest of geologists and one of the noblest of men.

WILLIAM NORTH RICE.

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GEOLOGY.

ITS AIM, SUBJECTS, AND DIVISIONS.

Aim of Geology. — Beneath the soil and waters of the earth's surface there is everywhere a basement of rocks. The rocky bluffs forming the sides of many valleys, the ledges about the tops of hills and mountains, and the cliffs along seashores, are portions of this basement exposed to view. Geology is the science that studies these rocks, not merely to learn about ore beds, coal, and building materials, but primarily to gather from them facts about the earth's history — the history of its rocks, features, and life. It is an outdoor science, and out of doors are found the best places of instruction for pupils and teacher.

Subjects of Study. — 1. *Making of Beds of Rock.* — In most of the rocky bluffs and ledges over the country, the rocks lie in successive beds. The beds differ in thickness and in other ways. They may be all sandstone, and show the grains of sand distinctly under a pocket lens. One or more of the beds may contain smoothly worn pebbles, with sand — the same material that constitutes a gravel bed; another may be a shale, so soft and fine-grained that, if ground up and mixed with water, it will make mud — suggesting that it might have been formed out of mud. The questions arise: How were the pebbles rounded? How were the mud, sand, and gravel distributed in beds? Whence the sand, pebbles, and mud?

At the foot of such a bluff there commonly lie heaps of loose sand and stones derived from the bluff. The rains, frost, and other causes keep wearing its surface, dropping grains, and tumbling down fragments; and thus the debris is formed. If a stream runs by the base of such a bluff, the water when in rapid flow will wear away and carry off the material, grinding and rounding the fallen fragments. If the bluff stands on a seashore, the waves beating against its exposed front will aid in the work of reducing it to sand, stones, and mud, for distribution by the waters off the shore and upon the beach.

All over the world the exposed rocks of hills, mountains, and plains are undergoing wear and decay, and becoming reduced to earth and coarser loose material. And, if the whole world is thus engaged, and has always been at this work since rocks were first exposed to the action of the air and waters, there ought to have been produced at all times, through period after period, not only loose material enough for making soil, but also for the formation of vast accumulations of sand beds, gravel beds, mud beds.

Along the bottom of a broad river valley, either side of the stream, there are beds of loose sand, gravel, and clay, lying in many alternations parallel with the surface. Up or down the valley, evidence may usually be found that the flowing waters are always at work, but especially in flood times, wearing stones to earth, and carrying down stream the ground-up material for deposition over the flats either side; evidence, therefore, that the rivers have made the beds which border them.

So again, along seashores, there are great deposits which the waters have made from the sand and pebbles supplied by the battered bluffs and from the sediment which the rivers carry to the ocean. They form wide sand flats off the shores, which are left bare by the retreating tides, and extensive mud beds and sand beds in the deeper waters, and beach deposits above tide level.

These river-made and sea-made beds are now unhardened; but the evidence gathered has made it certain that most of the hard rocks are similar deposits consolidated; that they were spread out in beds in the same ways in which beds are now formed along or off seashores, in river valleys, and in lakes. Nine tenths of the rocks studied by the geologist are water-made rocks. Nearly all the older water-made rocks are of marine origin, because, in early time, the ocean spread over the continents, leaving only islands to mark their sites. The continental seas were then the great workers; the little lands had only little rivers.

Again, rocky bluffs often consist in part or wholly of beds of limestone. Limestones are now being made where the seas abound in shells and corals. The process may be studied about the shores of Florida, at the Bahamas, and at Bermuda, as well as about many islands of the Pacific and the East Indies. The process is now going on, as in ancient time.

In many beds there are alternating ridges and furrows, like the so-called ripple-marks now often formed by the currents in shallow water; or cracks — though now filled — that were opened by the drying sun in an exposed mud flat; or impressions that were produced by the drops of a fall of rain. Such markings are records as to the origin of the rocks — the ripple-marks telling of their formation in shallow waters, or as sand flats; the mud-cracks showing that the rock, when soft mud, was exposed at times to the drying sun above the water's surface; the raindrop impressions teaching that it rained in ages long past, and that the bed so marked was a mud flat or a bed of fine wet sand, lying, during the storm, uncovered by the water. Thus, among the geological records, there are facts as to the depth of the waters, and meteorological records.

2. *Excavating Work of Waters.* — Over the earth's surface rivers work, not merely at transporting and making

deposits of sediment, but also at excavating channels over the land. And so they have worked in the past; and to them, in large part, the earth owes its valleys, great and small, the shapes of its ridges, and the manifold details of mountain scenery. Moreover, while doing this excavating work, the waters of the land have gathered much of their material for the making of rocks.

Part of the work of water, especially in later geological time, in both transportation and excavation, has been carried on by water in the state of ice, forming glaciers and icebergs.

3. *Fossils; Life.* — The beds, whether of sand, mud, or gravel, or of limestone, often contain shells, corals, bones, or remains of plants — fossils, as they are called, from the Latin word *fossilis*, signifying dug up. The shells or bones could not have got into the beds, except when the layer containing them was forming. They are like the shells in the mud or sand of existing sea bottoms or sand beaches, and bear evidence of the existence of life, and make known what species were living in the seas when the bed was made. The fossils of the lower and upper beds in the same bluff often differ, showing that, when the later beds were in progress, the old species had gone and new kinds had come in. Through the whole series of the earth's rocks new kinds continue to appear, and the old to disappear, on passing up from one level to another. Thus a history of the life of the globe, from the simplest species of the early rocks to man, has already been deciphered, and each year of further study is adding to its completeness. The history of the earth's life is the grandest subject of geological study.

But the fossils teach other lessons. As the species of successive periods differed, the kinds found in any rock are evidence as to its age. Again, they are evidence whether rocks are of marine origin or not; and thus they contribute facts as to the earth's early geography. They are often evidence, also, as to temperature or climate; for, as now, some species have required a warm, and others a cool temperature.

4. *Mountain-making.* — Rocks over large areas in many regions are now upturned and lifted into mountain ranges hundreds or thousands of miles long. The rocks show by their position that, in the mountain-making, they were pushed out of their original positions by some subterranean agency. The origin of mountains and the times of such upturnings are subjects for geological study.

The upturned rocks have sometimes become crystallized, or converted into marble, granite, mica schist, and the like; and such transformations furnish another subject of study.

5. *Fractures; Veins; Volcanoes; Geysers.* — Again, in many regions the earth's crust has been deeply fractured. Sometimes mineral veins have formed in the fissures. Often melted rock, from unknown depths, has come to the surface and spread widely over it, thus adding fire-made, or igneous, rocks to those which are water-made. Occasionally volcanoes have formed over the larger fissures; and in a few places geyser regions, like that of the Yellowstone Park, have been left as residual effects of volcanic action.

From the above explanations it is obvious that several great subjects are treated under Geology.

(1) The characteristics of the rocks of the globe.

(2) The historical succession in the formation of the rocks.

(3) The origin of the rocks.

(4) The origin of rivers, lakes, and seas.

(5) The origin of mountains, igneous eruptions, volcanoes, and of fractures in the earth's crust and changes of level.

(6) The history of continent-making, and the origin of the system in the arrangement of the earth's coast lines, its mountain chains, and its island ranges.

(7) The history of the earth's climates.

(8) The history of life.

In the study of these subjects, Geology assumes with good reason that the physical forces now in action have been the same, and under the same laws, through all past time. Whether those of the waters, the winds, heat, cohesion, or of whatever kind, these forces have produced results through the ages like those observed about us, with little difference except that some forces must have acted with greater, and others with less, intensity in early geological time. Existing nature, therefore, affords the means of interpreting the geological records.

Divisions of the Science. — The divisions of the science here adopted are the following: —

1. **Physiographic Geology.** — Treating of the earth's physical features; that is, of the system in the exterior features of the earth. This department properly includes also the system of movements in the water and atmosphere, and the system in the earth's climates, and in the other physical agencies or conditions of the sphere.

2. **Structural Geology.** — Treating of the rocks of the globe, their kinds, structure, and arrangement in beds or otherwise.

3. **Dynamical Geology.** — Treating of the causes, or the methods, by which all the earth's changes were brought about, including the making of continents, of ocean basins, of rocks, of mountains, of valleys; the causes of all variations in climate, and of all changes in the earth's features, and of the system in the progress of life. The word *dynamical* is from the Greek δύναμις, power or force.

4. **Historical Geology.** — Treating of the successive events in the history of the rocks, and of the continents, oceans, mountains, valleys, coast lines, climates, and life.

PART I. — PHYSIOGRAPHIC GEOLOGY.

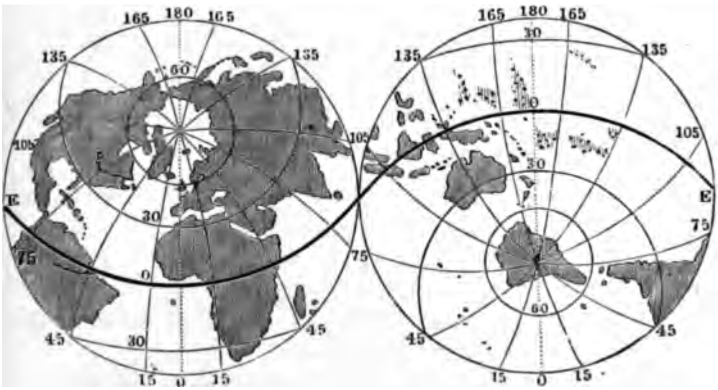
I. GENERAL FEATURES OF THE EARTH'S SURFACE.

Size and Form. — The earth has a circumference of about 25,000 (24,899) miles. Its form is that of a sphere flattened at the poles, the equatorial diameter (7926 miles) being about $26\frac{7}{8}$ miles greater than the polar diameter.

Regions of Depression and Elevation. — About eight elevenths of the earth's surface, or 144,000,000 square miles, is depressed below the rest, and occupied by salt water. This sunken part of the crust is called the oceanic basin, and the large areas of land are called the continents or continental plateaus. The area of the continents and islands is about 52,745,000 square miles.

Arrangement of Oceans and Continents. — Nearly three fourths of the area of the continental plateaus is situated in the northern hemisphere, and very nearly three fifths of the oceanic basin in the southern hemisphere. The dry land, as shown in the map, Fig. 1, may be said to be grouped about the North Pole, and to stretch southward in two masses, an Oriental, including Europe, Asia, Africa, and Australasia, and an Occidental, including North and South America. The ocean is gathered in a similar manner about the South Pole, and extends northward in two broad areas separating the Occident and Orient, namely, the Atlantic and Pacific Oceans, and also in a third, the Indian Ocean, separating the southern prolongations of the Orient, namely, Africa and Australasia. The Orient is made, by this arrangement, to have two southern prolongations, while the Occident, or America, has but one. This double feature of the Orient accords with its great breadth; for it averages 6000 miles from east to west, which is far more than twice the mean breadth of the Occident (2200 miles). The inequality of the two continental masses has its parallel in the inequality of the Pacific and Atlantic oceans; for the former (6000 miles broad) is more than double the average breadth of the latter (2800 miles).

Fig. 1.



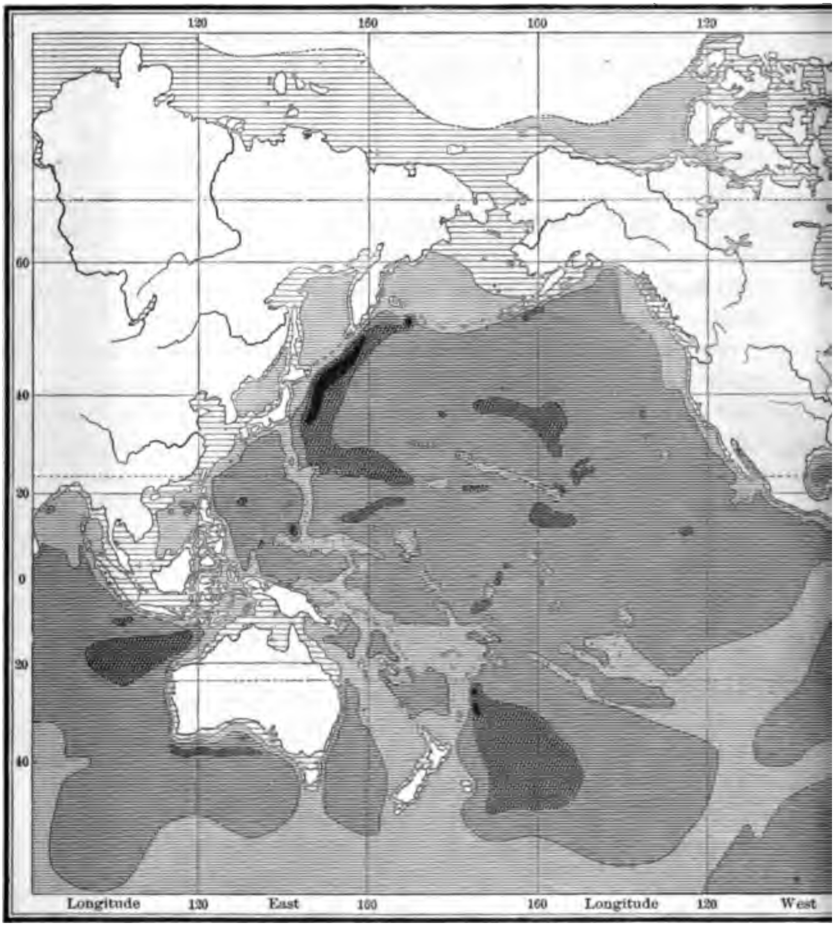
Land hemisphere and water hemisphere.

The northern portion of the Orient, or Europe and Asia combined, makes one continental area, Eurasia; its general course is east and west. The northern portion of the Occident, North America, is elongated from north to south.

Depth of Oceans and Height of Continents.—The mean depth of the oceanic depression is about 14,000 feet; and the mean height of the land (according to Murray) 2252 feet. The greatest depth reached by soundings (south of the Friendly Islands) is 30,930 feet; the greatest height on the land (Mt. Everest of the Himalayas) is 29,000 feet; hence the interval between the extremes of altitude and depression is over eleven miles. If the continental plateaus and the floor of the ocean were graded to a common level, the ocean would still have a depth of about 10,000 feet. The mean height of Europe is (according to Murray) 939 feet; Asia, 3189 feet; Africa, 2021 feet; Australia, 805 feet; North America, 1888 feet; South America, 2078 feet. The mean depths of the great oceans are: of the North Atlantic, 15,000 feet; North Pacific, 16,000 feet; South Atlantic and South Pacific (and probably the Indian Ocean), about 13,000 feet.

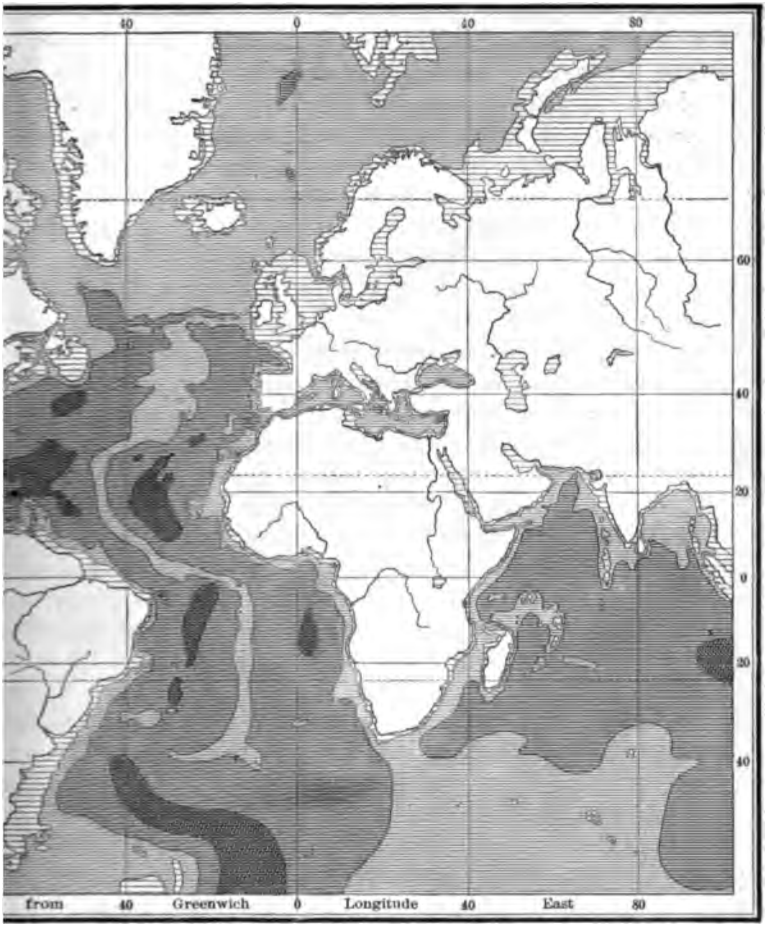
The Form of the Ocean's Bed. — Fig. 2 shows the general form of the ocean's bed beneath the larger oceans. From north to south, along the middle of the Atlantic, there is a wide zigzag ridge or plateau, conforming nearly in trend to the American coast. It lies at a depth of 6000 to 12,000 feet, while on either side the bottom slopes away to depths mostly between 15,000 and 20,000 feet. In the area of 4000 fathoms and over, situated north of the island of Puerto Rico, the United States Coast Survey steamer Blake found, in 1883, a depth of 27,366 feet. This greatest depth, and large areas of deep water, exist in the western part of the ocean. In the Pacific Ocean, a shallow area extends, with little interruption, from the Malay Archipelago southeastward beyond the Paumotu Islands, and thence northeastward to the Isthmus of Panama, southeastward to Patagonia, and southward to the Antarctic. The deepest parts of this ocean also are in its western half. One deep area is east of Japan; another, south of the Ladrones; others, near the Friendly Islands. Northward in the northern hemisphere the ocean shallows rapidly. The depth in Bering Strait is not over 150 feet; and between Great Britain and Iceland it does not exceed 6000 feet, and is mostly under 3000 feet.

The ocean's bottom has no steep ridges like those of ordinary mountain scenery. But broad elevations exist in some parts, as found in the soundings of the Tuscarora between the Hawaiian Islands and Japan. Besides these, Fig



0-100 fathoms *100-2000 fathoms* *2000-*

BATHYMETRIC CHA



ms *3000-4000 fathoms* *4000 fathoms and over*

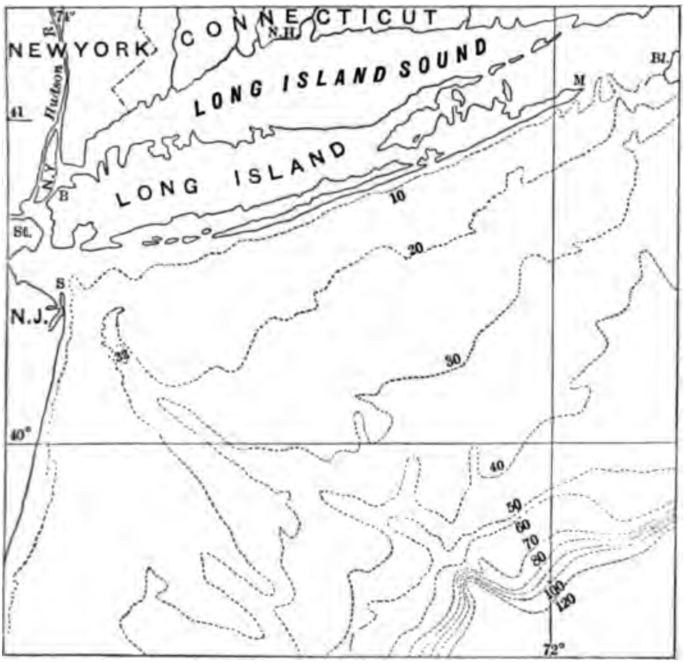
F THE OCEANS

there are many mountain ranges rising somewhat abruptly from the depths, having the islands of the ocean as their summits, which rival in length those of the continents. The Hawaiian range, if the coral islands in the line of the volcanic islands are included (see Fig. 2), has a length of 2000 miles; and it rises steeply from depths of 15,000 to 18,000 feet. The mountains of Hawaii have a height above the ocean of nearly 14,000 feet, and a depth of 17,000 feet was found but 50 miles south of the island, thus making the whole height nearly 31,000 feet. The islands of the tropical Pacific make together an island chain about 5000 miles long; and they are the tops of a mountain chain of this great length.

True Outline of the Oceanic Depression.—Along the oceanic borders, the sea is often, for a long distance out, quite shallow, because the continents continue on under water with a nearly level surface; then comes, usually at a depth of about 100 fathoms, or 600 feet, a rather sudden slope to the deep bed of the ocean. This is the case off the eastern coast of the United States, east and south of New England. Off New Jersey, as is shown by Fig. 3, the deep water begins along a line about 80 miles from the shore; off Virginia this line is 50 to 60 miles at sea; and thus it gradually approaches the coast to the southward: while to the northward it continues 80 to 100 miles off from the New England coast, and passes far outside of Nova Scotia and Newfoundland (see Fig. 2). The slope of the bottom, for the 80 miles off New Jersey, is only 1 foot in 700 feet. The true boundary between the continental plateau and the oceanic depression is the commencement of the abrupt slope. The same abrupt slope near the 100-fathom line exists in the Gulf of Mexico. The British Islands are situated on a submerged portion of the European continent, and are essentially a part of that continent, the limit of the oceanic basin—the 100-fathom line—being 50 to 100 miles outside of Scotland and Ireland, and extending south around the

Bay of Biscay. West of the English Channel the depth increases, in a distance of only ten miles, from 100 fathoms to 2000. New Guinea is in a similar way proved to be a part of Australia. Such facts occur on most coasts; and they teach that the oceanic depression is generally separated from the continental plateaus by a well-defined outline.

FIG. 8.



Bathymetric chart of region south of Long Island.

Surfaces of the Continents. — The surface of a continent comprises (1) *plains* or *lowlands*, (2) *plateaus* or *table-lands*, and (3) *mountain ridges*. The mountain ridges may rise either from the lowlands or the plateaus. The plateaus are large areas of approximately level surface at an altitude of a thousand feet or more above the sea. They are often parts of the great mountain chains, lying between the ridges, or forming the mountain mass out of which the ridges rise. For example, the regions of northern and southern New York are plateaus (the former averaging 1500 feet in height, the latter 2000 feet) situated on the western borders of the Appalachian chain; and the same is true of the Cumberland table-land in Tennessee. Between the Sierra Nevada and the Wasatch, there is a plateau of vast extent, called the Great Basin, having the Great Salt Lake in its northeastern portion; its height above the sea averages 4000 feet; the Humboldt Mountains and other high ranges rise out of it. It continues northward into British America and southward into Mexico. The eastern part of New Mexico, with the western part of Texas, is a plateau of about the same elevation, called the Llano Estacado. The Desert of Gobi, between the Altai and the Kuen-Lun range, is a desert plateau about 4000 feet high, while the plateau of Tibet, between the Kuen-Lun range and the Himalayas, is 11,500 to 13,000 feet above the sea. Persia and Armenia constitute another plateau. These examples are sufficient to explain the use of the term.

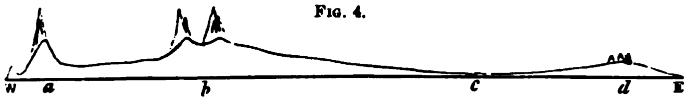
II. SYSTEM IN THE EARTH'S FEATURES.

General Relief of the Continents. — The continents are constructed on a common model: they have high borders and a low center, and are, accordingly, basin-shaped. North America has the Appalachians on the eastern border, the Cordillera on the west, and between these the low Mississippi basin. Fig. 4 illustrates this form of the continent. In the section, *b* represents the Rocky Mountain chain on the west, with its lines of ridges at summit; *a*, the Sierra chain (including the Sierra Nevada and Cascade Range), near the Pacific coast; *c*, the Mississippi basin; *d*, the Appalachian chain on the east.

South America, in a similar manner, has the Andes on the west, the Brazilian Mountains on the east, and other heights along the north, with the low region of the Amazon and La Plata making up the larger part of the great interior. Fig. 5 is a transverse section from west to east, showing the Andes at *a*, and the Brazilian Mountains at *b*. In these sections the height as compared with the breadth is necessarily much exaggerated.

In the Orient there are mountains on the Pacific side, others on the Atlantic; and, again, the Himalayas, on the south, face the Indian Ocean, and the Altai Mountains

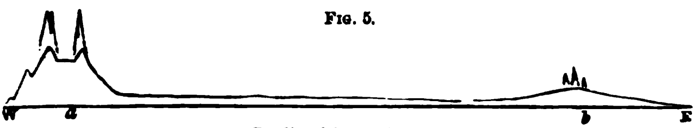
FIG. 4.



Profile of North America.

face the Arctic seas. Between the Himalayas (or rather the Kuen-Lun Mountains, which are just north) and the Altai, lies the plateau of Gobi, which is low compared with the inclosing mountains; and farther west there are the lowlands of the Caspian and Aral, the Caspian lying even below the level of the ocean. The Urals divide the 6000 miles of breadth into two parts, and so give Europe some

FIG. 5.



Profile of South America.

title to its designation as a separate continent. West of their meridian there are again extensive lowlands over middle and southern European Russia. In Africa there are mountains on the eastern border, and on the western border south of Guinea; there are also the Atlas Mountains along the Mediterranean, and the Kong Mountains along the Guinea coast; and the interior is relatively low, although mostly 1000 to 2000 feet in elevation. In Australia, also, there are highlands on the eastern and western borders, and the interior is low. All the continents are, therefore, constructed on the basin-like model.

The Greater Mountains border the Greater Ocean. — There is a second great truth with regard to the continental reliefs: the highest border faces the largest ocean. Each of the continents sustains the truth announced. North America has its great mountains, the Cordillera, on the side of the great ocean, the Pacific; and its small mountains, the Appalachians, on the side of the small ocean. South America, also, has its highest border on the west. The Orient has high ranges of mountains on the east, or the Pacific side, and lower ranges, as those of Norway and other parts of Europe, on the west; and the Himalayas face the great Indian Ocean, while the smaller Altai range faces the small Northern Ocean. In Africa, the mountains on the side of the Indian Ocean are higher than those on that of the Atlantic. In Australia the highest border is on the Pacific side; for the South Pacific fronting east Australia, is greater than the Indian Ocean fronting west Australia. Hence the basin-like shape before illustrated is that of a basin with one border much higher than the other; and with the highest border on the side of the largest ocean.

The features described have a vast influence in adapting the continents for man. America has its highest border in the far west, with all its great plains and great rivers inclined toward the Atlantic; for, through the Gulf of Mexico, the whole interior, as well as the eastern border, has its natural outlet eastward. The Orient, instead of rising into Himalayas on the Atlantic border, has its great heights in the remote east; and its vast plains, even those of Central Asia, have their natural outlet westward, over Europe and through the Mediterranean, or toward the same Atlantic Ocean. Thus, as Professor Guyot has said, the vast regions of the world, which are best fitted for man, by their climate and productions, are combined into one great arena for the progress of civilization.

PART II. — STRUCTURAL GEOLOGY.

THE term *rock*, in geology, is applied to all natural formations of mineral material, whether consolidated, like sandstones and slates, or unconsolidated, like sand and gravel. All sandstones were once beds of loose sand; and there is every shade of gradation, from the hardest sandstone to the softest sand bed; so that it is impossible to draw a line between the consolidated and the unconsolidated. Geology does not attempt to draw the line, regarding consolidation as an accident in the history of the earth's beds or deposits — an accident that probably happened to only a small part of the sand beds and mud beds that have existed, and yet to enough of them in each period for the preservation of the wonderfully varied records that are the materials of geological science.

Rocks may be studied simply as rocks, — that is, with reference to their composition, — and collections may be made containing specimens of their various kinds. Again, they may be studied as rock masses spread out over the earth and forming the earth's crust; and, with this in view, the condition, structure, and arrangement of the great rock masses, called *terranes*, would come up for consideration. The two subjects under Structural Geology are, therefore: —

1. THE CONSTITUTION OF ROCKS.
2. THE CONDITION, STRUCTURE, AND ARRANGEMENT OF ROCK MASSES, OR TERRANES.

I. CONSTITUTION OF ROCKS.

Minerals.

Rocks are generally heterogeneous, being composed of grains or particles of different materials. The separate grains or particles, which are homogeneous or nearly so, having a definite chemical constitution, are called minerals. The minerals which constitute the principal ingredients of the common rocks are included in three groups: —

1. SILICA, or silicon dioxide.
2. SILICATES, or compounds of silicon and oxygen with other elements.
3. CARBONATES, or compounds of carbon and oxygen with other elements.

Besides these, three other groups of minerals should here be mentioned, as sometimes constituting rock masses, and including materials of special importance: —

4. CARBON AND ITS COMPOUNDS (other than carbonates).
5. CHLORIDES.
6. IRON ORES.

1. SILICA.

Silica, or silicon dioxide (SiO_2), in its most common molecular arrangement, constitutes the mineral *quartz*, which far exceeds all other minerals in abundance. It is one of the hardest of common minerals; does not melt before the blowpipe, and does not dissolve in water, or in the ordinary acids.

FIG. 6.

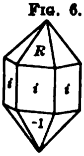
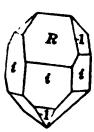


FIG. 7.



Quartz.

It is often seen in crystals like Figs. 6, 7, though generally occurring in massive forms, or in grains or pebbles. It is distinguished ordinarily by its glassy aspect, whitish or grayish color, and an absence of all tendency to break with a bright even surface of fracture (a quality possessed by many crystals, called cleavage). Although usually nearly colorless or white, it is often reddish, yellowish, brownish (especially smoky brown), and even black; and the luster is sometimes very dull, as in chalcedony, flint, and jasper. The sands and pebbles of the seashores and gravel beds are mostly quartz; because quartz resists the wearing action of waters better than any other common mineral. For the same reason, most sandstones and conglomerates consist mainly of quartz.

The hardness (on account of which it scratches glass easily), infusibility, insolubility in acids, and absence of cleavage, are the characters that serve to distinguish quartz from the other ingredients of rocks.

But, though quartz is so refractory, it easily fuses into glass when mixed with potash, soda, lime, or an oxide of iron. Ordinary glass is made by mixing powdered quartz with soda and sometimes lime, and subjecting the mixture to a high heat.

Silica exists also in a different molecular state, in which it is called *opal*. Opal, a beautiful gem in some of its varieties, does not occur crystallized, has a little less hardness than quartz, and is more easily soluble in a heated alkaline solution. The silica secreted by some minute plants, as Diatoms, and by Sponges and Radiolarians among animals, is opal; and in many places large beds of the minute shells and spicules are formed by the growth and death of the above-mentioned organisms (see page 106).

2. Silicates.

Most of the common rock-making minerals are silicates; that is, combinations of silicon and oxygen with certain basic elements, as aluminium, magnesium, calcium, potassium, sodium, iron, and a few others.

The silicates which contain no metal except aluminium are infusible as well as very hard. But those which contain one or more of the other metals mentioned are with few exceptions fusible.

The following are the most common of these silicates: —

1. **Feldspar.** — The feldspars are silicates of aluminium with one or more of the metals potassium, sodium, and calcium. They are hard enough to scratch glass, but less hard than quartz. They break easily, or have cleavage, in two directions, and the two lustrous cleavage surfaces meet nearly or quite at a right angle. The color is usually white or flesh-red, rarely dark brown or greenish. The specific gravity is 2.4 to 2.7.

The most common kind is a potash feldspar, affording on analysis silica, alumina, and potash, and is called *orthoclase;* another, named *albite*, from its usual white color, is a soda feldspar; others, as *oligoclase*, *andesine*, and *labradorite*, are soda-lime feldspars.

2. **Mica.** — Mica is a silicate of aluminium and potassium, but some kinds of mica contain also magnesium and iron. Mica cleaves easily into tough leaves, thinner than the thinnest paper, and somewhat elastic; it fuses with great difficulty; hence its common use in lanterns and doors of stoves. Its most common colors are whitish, brownish, and black. The most common kind of mica has a light color, and is called *muscovite*, from its old name, Muscovy glass; another, usually black in color, is called *biotite.* Some micas are hydrous; that is, they contain water; and these *hydromicas*, as they are called, are pearly in luster, feel a little soapy, and are sometimes mistaken for talc.

The minerals, quartz, feldspar, and mica, are the constituents of granite; and they may be distinguished in it as follows: the grains of quartz, by their glassy luster, gray color, and want of cleavage; the grains of feldspar, by their shining cleavage, as is well seen when a surface of fracture is held up to the sunlight; the grains of mica, by their very easy cleavage by means of the point of a knife blade into thin elastic leaves.

3. **Hornblende and Pyroxene.** — Hornblende and pyroxene are silicates of magnesium, calcium, and iron, aluminium not being an essential constituent, and, when present, always in small amount. The most common variety of each of these minerals, occurring as a principal constituent of rocks, is black, or greenish black, and 2.9 to 3.5 in specific gravity; but white and light green varieties also are common. They are somewhat inferior to feldspar in hardness; unlike mica, they are brittle. The crystals or crystalline grains have two equally lustrous cleavages. In hornblende, the angle between the two is about 124°; in pyroxene, about 87°. Hornblende is often in long, slender crystallizations, and asbestus is a very fine fibrous variety of it, sometimes like wool. Both hornblende and pyroxene make hard and tough rocks. Pyroxene is a constituent of some of the most common igneous rocks.

4. **Chrysolite.** — A silicate of magnesium with some iron. It is generally of an olive-green color, and occurs in many igneous rocks in disseminated grains or crystals, looking much like bits of green bottle glass.

5. **Chlorite.** — A silicate of magnesium, aluminium, and iron, containing generally 12 per cent or more of water. It resembles black mica in its crystallization and cleavage; but its folia are not elastic, its color is usually dark green, and it feels a little greasy. It is often finely granular.

6. **Talc; Serpentine.** — Talc and serpentine are hydrous silicates of magnesium; that is, silicates containing water. They both have a greasy feel — especially talc. Talc is very soft, so soft that it does not feel gritty to the teeth. It is often in foliated plates or masses like mica; but the folia, or leaves, though separating rather easily, and flexible, are not elastic. The usual color is pale green. Soapstone, or steatite, is a massive variety of talc, of whitish, grayish, or greenish color.

Serpentine contains much water (about 14 per cent). It is usually a dark green massive mineral or rock, of smooth fracture, and soft enough to be cut with a knife.

7. The following minerals occur distributed in crystals through many crystalline rocks, though rarely forming the principal constituents of rocks: —

Garnet. — The most common varieties are silicates of aluminium, with iron, calcium, or magnesium. They occur often in dark red, brownish, or black crystals of 12 or 24 sides (dodecahedrons or trapezohedrons). The first of these forms is represented in Fig. 8, showing garnets distributed through a mica schist.

FIG. 8.

Garnet.

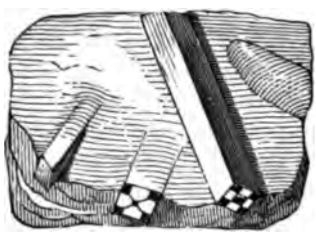
Tourmaline contains, besides silicon and oxygen, aluminium, magnesium, iron, boron, and fluorine. It occurs generally (Fig. 9) in crystals which are prisms of 3, 6, 9, or 12 sides; the most common color is black, but it is sometimes blue-black, brown, green, or red.

Andalusite is simply an aluminium silicate, and hence is infusible. It is found in imbedded crystals in clay slate, and sometimes in mica schist; the form is nearly a square prism. The interior of the crystals is very frequently black or grayish black at the center and angles (Fig. 10), while the rest is nearly white; and this variety is called macle, or chiastolite.

FIG. 9.

Tourmaline.

FIG. 10.



Andalusite.

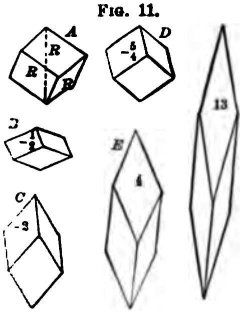
Cyanite has the same composition as the preceding, and like it is infusible. It usually occurs in mica schist or gneiss, in thin, bladelike, pale blue crystals.

Staurolite. — Related to the last two minerals, and infusible; but it contains some iron. Its crystals are stout prisms of about 129°, of brown or brownish black color; they often have the form of a cross, whence the name, from *σταυρός*, a cross.

3. Carbonates.

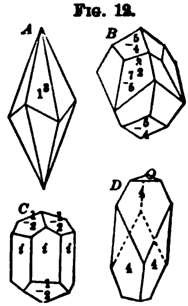
1. **Calcite,** or Calcium carbonate ($CaCO_3$). — The material of limestone and marble. It crystallizes in many forms, a few of which are represented in Figs. 11 and 12. It cleaves easily in three directions with bright surfaces, as may be seen on examining even the grains of a fine white marble. Its colors are various. It is so soft as to be easily scratched with a knife; dissolves in diluted

Fig. 11.



Calcite.

Fig. 12.



Calcite.

acid (hydrochloric) with effervescence, that is, with an escape of carbonic acid gas (CO_2); and, when heated (as in a limekiln or before the blowpipe), it burns to quicklime without melting. By its effervescence with acids it differs from all the minerals before mentioned.

2. **Dolomite,** Calcium-magnesium carbonate ($CaMgC_2O_6$), differs from calcite in containing magnesium in place of part of the calcium. Very much of limestone is magnesian limestone. It closely resembles ordinary limestone, but may be distinguished by its effervescing scarcely at all with acid unless heat be applied.

For iron carbonate (siderite) see page 27.

4. Carbon and its Compounds (other than Carbonates).

Carbon occurs pure among minerals only in *diamond* and *graphite*. It is the chief element in *mineral coal*, but is combined in it with more or less of hydrogen and oxygen, and also some nitrogen. Charcoal, the *carbo* of the Romans, is nearly all carbon.

Carbon occurs in the atmosphere in the form of carbon dioxide, or carbonic acid (CO_2). This gas constitutes about 3 out of 10,000 parts of the atmosphere, and is carried from the atmosphere to the earth by the rains. It is formed in the combustion of wood, the combustion consisting in the combination of oxygen with the constituents of the wood. It is also given out in the respiration of animals, the processes of life in animals being carried forward through a sort of combustion, or a similar combination of oxygen with the materials of the tissues.

Aside from its occurrence in the carbonates, the chief form in which carbon occurs as a rock material is that of mineral coal.

1. **Diamond and Graphite.** — These are both pure carbon, but in different molecular states; the former, the hardest of minerals, crystallizing in octahedral and related forms; the latter, one of the softest, crystallizing in hexagonal plates, with nearly the easy cleavage of mica, and with metallic luster. Graphite is also called plumbago and black lead, and is the material of the misnamed lead pencils. It occurs in crystalline rocks in scales and masses, and is ground up and subjected to pressure to prepare it for making pencils.

2. **Mineral Coal.** — Mineral coal is not a true mineral, being not a definite chemical compound, but a mixture of various compounds of carbon with hydrogen and oxygen. It constitutes beds in various rock formations, and has been formed from wood or some kind of vegetable material. There are three prominent kinds, differing in the amount of oxygen and hydrogen that is present with the

chief ingredient carbon, and consequently in the amount of inflammable gas given out in burning. This gas consists chiefly of carbon and hydrogen, and is essentially the same as the gas used in illumination.

1. *Anthracite* contains generally over 85 per cent of carbon. It yields little that is volatile, and burns with a feeble blue flame.

2. *Bituminous coal* has less hardness and luster than anthracite, contains usually 65 to 85 per cent of carbon, and gives out on heating 20 to 50 per cent of volatile matter. It therefore burns with a bright yellow flame. When heated, it will yield illuminating gas, and also mineral oil. Cannel coal is a compact bituminous coal having a feeble luster; it often yields 40 to 50 per cent of volatile matter, and is an available source of mineral oil. Bituminous coal is called caking coal when it softens in the fire and cakes at the surface, so that a fire made of it requires poking to make it burn freely; non-caking kinds have not this quality, and hence are preferable for fuel.

3. *Brown coal* differs from bituminous coal in yielding a brownish black powder, and in containing much more oxygen (20 to 30 per cent or more). The mineral coal from rocks more recent than the Carboniferous formation is often improperly called brown coal, even when it is good bituminous coal, without a brownish color to the powder. The name *lignite* is sometimes also applied to it; but true lignite is coal that retains the fibrous texture of the original wood.

3. **Mineral Oil.** — This consists of liquid hydrocarbons, and is chemically related to illuminating gas. It was formed out of animal or vegetable materials. Illuminating gas is often given off in great quantities from the wells or sources yielding mineral oil, and in some villages, in oil regions, the houses are heated and lighted by it. Many black shales yield mineral oil when heated. They do not contain the oil, but contain other hydrocarbons

(not yet satisfactorily investigated) which yield the oil on heating. Mineral oil, on long exposure to the air, combines with oxygen, and may ultimately become a black fusible bitumen, or a coal-like substance having little or no fusibility.

5. Chlorides.

The only chloride forming rock masses is —

Common Salt, or **Rock Salt.** — It is sodium chloride ($NaCl$). It is easily distinguished by its taste. It constitutes beds, more or less impure, in strata of various ages from the Silurian to recent time; which is accounted for by the fact that the universal ocean is an abundant source of salt, and only evaporation is required to deposit it. Silurian rock salt occurs in western New York, and Upper Canada; and a great deposit, probably of Cretaceous age, nearly 40 feet thick and remarkably pure, occurs at Petit Anse, Louisiana, near the Gulf of Mexico. The saline constituents of the ocean's waters constitute about 3.53 parts in 100; of which about three fourths is common salt, the rest being chiefly magnesium chloride, magnesium sulphate, calcium sulphate, or gypsum, potassium sulphate, magnesium bromide, and calcium carbonate, with traces also of other ingredients.

6. Iron Ores.

Iron ores are widely distributed in the rocks, and some of them form thick beds. Unlike the minerals mentioned above, they have a specific gravity above 3.5. The most important are three oxides, three sulphides, and a carbonate.

The sulphides, however, are never used in the manufacture of iron, since no process is known by which iron can be economically separated from sulphur.

1. **Hematite,** or ferric oxide (Fe_2O_3). — It yields a red powder, whence its name, given it by the old Greeks, from *αἷμα*, blood. Its crystals have usually an iron-black

color, and high luster; but it is deep red when earthy or impure. It is the source of the color in red sandstones and some other red rocks.

2. **Limonite,** or hydrous ferric oxide, includes two equivalents of Fe_2O_3 united with three equivalents of water. It varies in color from black to brown and yellow, but yields always a brownish yellow powder. While red ocher of painters is impure hematite, yellow ocher is impure limonite. Limonite is the coloring ingredient in a large part of brown and brownish yellow rocks and clays. The water present goes off on heating, and hence the mineral, and all rocks colored by it, when heated, turn red. It is formed from the oxidation and hydration of various iron-bearing minerals (page 111), and often makes deposits in marshes (page 116).

3. **Magnetite.** — Magnetite has an iron-black color, like hematite; but, unlike that ore, it is attracted strongly by a magnet, and yields a black powder. It consists of three atoms of iron and four of oxygen (Fe_3O_4). It is common in grains in many rocks (not in limestones), and among the sands of seashores and soils; and, like hematite, constitutes great beds among the older rocks.

Ferrous oxide (FeO) never occurs as a mineral.

4. **Pyrite; Marcasite; Pyrrhotite.** — Pyrite is an iron sulphide (FeS_2), of a brass-yellow color, and nearly as hard as quartz. It will strike fire with steel, and was named by the Greeks from *πῦρ*, fire. It is common in rocks, in massive forms, crystals (often cubes), and grains. Marcasite has the same composition as pyrite, but a different crystalline form. Pyrrhotite is the name of another common iron sulphide, containing proportionally less sulphur ($Fe_{11}S_{12}$), having the color of bronze, so soft as to be easily scratched with the point of a knife, and somewhat strongly attracted by a magnet.

5. **Siderite.** — This mineral, called also iron carbonate ($FeCO_3$), and spathic iron, has, when crystallized, approximately the cleavage and form of calcite. The color is

light gray, but changes readily to brown on exposure (by alteration of more or less of the material to limonite). It is much heavier than calcite, its specific gravity being 3.7 to 3.9. It effervesces, like dolomite, in heated dilute hydrochloric acid.

The ironstone, or clay ironstone, of coal regions, used as an ore of iron, is generally siderite; that of other than coal regions is commonly hematite or limonite.

Kinds of Rocks.

Preliminary Definitions.

Fragmental and Crystalline Rocks. — The minerals of which a rock consists may be either (1) in broken or worn grains or pebbles, like those of sand or mud or a bed of gravel; or (2) in crystalline grains, in which case they were formed where they now are at the time of the crystallization of the rock. Such crystalline grains are angular, as may be seen on a surface of fracture, and, in the case of most minerals excepting quartz, show surfaces of cleavage. Common white marble and granite are good examples of rocks having a crystalline texture; and, among products of art, such a texture is shown in loaf sugar and steel.

The rocks of the first kind, consisting of fragments of other rocks, are called fragmental rocks; and those of the latter kind, crystalline rocks. Fragmental rocks are also called clastic rocks, from the Greek κλάζω, to break.

Besides rocks that are obviously fragmental and those obviously crystalline there are others, of flinty compactness, which show no distinct grains, and are therefore not easily referred to either division. To determine the division to which such rocks belong, they must be studied in relation to the rocks associated with them. If these associated rocks are fragmental, then the compact beds are probably so also; but, if these are crystalline, then the compact beds are probably crystalline. The examination of thin transparent slices with the microscope is often the only means of distinguishing the two kinds.

Fragmental Rocks. — These are the most common of rocks, constituting by far the largest part of the strata accessible to geological study. The wear and decomposition of the oldest rocks produced fragmental material for those of the next period, and so on through geological time; and the rocks made of such material, as, for example, sandstones, shales, and conglomerates, are fragmental rocks. They are stratified rocks also, because they are in beds. They are also called sedimentary rocks, because the material was in most cases deposited as a sediment from waters; and detrital rocks, because composed of the worn-out material (*detritus*) of older rocks.

While the great majority of fragmental rocks were formed as sediments from water, others have been formed of material transported by glaciers (see page 162) or by wind (see page 120). Still other fragmental rocks have resulted from the accumulation of the broken rocks, cinders, and ashes discharged in the explosive phase of volcanic eruptions.

Crystalline Rocks are either igneous or metamorphic (with the exception of comparatively small accumulations in veins and elsewhere, formed by deposit from solution).

Igneous Rocks include those which have come up melted through volcanic vents, or through fissures opened to some seat of melted rock within the earth's crust. Besides those which have solidified at or near the surface, other igneous rocks have solidified at considerable depth below the surface. Such rocks must of course underlie all superficial rocks. Igneous rocks solidified at great depth may subsequently be laid bare by extensive erosion. Igneous rocks include lavas, most porphyry and granite, and other rocks described later (pages 36–39).

The igneous rocks which have solidified at or near the surface are called *volcanic rocks;* those which have solidified at great depth, *plutonic rocks.* In their more typical forms, the two groups are strongly distinguished from each other, though indefinite gradations exist between them. Plutonic rocks have cooled slowly; and the molecules have therefore had time to arrange themselves into crystalline grains of comparatively large size. Such rocks are therefore somewhat coarsely crystalline. Volcanic rocks have cooled rapidly, and the process of molecular arrangement was therefore interrupted by solidification before large crystals could be formed. Such rocks are therefore fine-grained, and more or less of the material (sometimes nearly the whole) is amorphous or glassy. Plutonic rocks have cooled under great pressure. Thin sections examined under the microscope show innumerable minute cavities, filled most commonly with water, more rarely with carbon dioxide or some other material, partly in liquid condition, but with a bubble of the same material in gaseous form floating in the liquid. Volcanic rocks have cooled under little more than atmospheric pressure. In such rocks fluid cavities are wanting, since volatile materials enveloped in the mass have been able to escape.

The name *lava* is applied to volcanic rocks in general, especially to those which have come from recent volcanoes, and to those which show a vesicular or scoriaceous structure (page 175).

Metamorphic Rocks have assumed their present structure under the action of heat and other subterranean agencies without fusion. The rocks so changed were probably in most cases ordinary fragmental rocks and limestones. The alteration, when most perfect, has consisted in a complete crystallization of the rock, and, when least so, in its consolidation; between which extremes all gradations exist. Examples of metamorphic rocks are marble, mica schist, gneiss, and (probably) some granite.

While metamorphic rocks have probably been derived for the most part from the alteration of sedimentary rocks, it appears certain that in some cases rocks generally included under this category have been formed by a re-arrangement of the materials of igneous rocks.

Massive Rocks. — Rocks are termed massive when there is no tendency to part along parallel planes, so as to form slabs or plates. This is the case in general with the coarser fragmental rocks, as sandstones and conglomerates, with most igneous rocks, and with many limestones.

Laminated, Shaly, Slaty, Schistose Rocks. — All these terms express a tendency of the rock to part along parallel planes, so as to form slabs or plates.

In laminated and shaly rocks, the planes of division are those of deposition of the material. These structures belong, accordingly, to sedimentary rocks, and are characteristic of the fine-grained sediments. The shaly structure differs from the laminated in that the plates in the former are thinner and more fragile.

In slaty rocks, the planes of division, or cleavage, are independent of the planes of deposition, and may cross the latter at any angle. The slaty structure is the result of pressure subsequent to the deposition and consolidation of the rock.

In schistose (or foliated) rocks, the planes of division are determined by the parallel arrangement of crystalline grains of some cleavable mineral, as mica, hornblende, talc, or chlorite. This structure is characteristic of most of the metamorphic rocks. In many cases, it is undoubtedly the result of the original stratified arrangement of the material in a sedimentary rock. But in other cases such a parallel arrangement appears to be due to pressure or shearing, causing a rearrangement of the materials of the rock. A schistose structure may, accordingly, be developed in rocks of igneous origin or in vein deposits.

The rocks exhibiting most typically the laminated, shaly, slaty, and schistose structures are called respectively flagstones or flags, shales, slates, and schists.

Porphyritic Rocks. — A porphyritic rock is one having distinct crystals (usually of feldspar) disseminated through a fine-grained or compact mass, so that, when polished, the surface shows angular spots of a light-colored mineral, usually between an eighth of an inch and two inches in length. These disseminated crystals are called phenocrysts. The red porphyry of Egypt, and the green porphyry of the eastern borders of Greece, much used for ornamental purposes by the ancients, are typical examples. This structure is very frequent in felsite, but occurs also in granite and many other rocks. It is especially characteristic of igneous rocks. The phenocrysts formed slowly, while the remainder of the material was still fluid. Later, under other conditions, the remainder of the rock solidified more rapidly, forming the fine-grained or compact mass.

Calcareous Rocks. — Calcareous rocks, so named from the Latin *calx*, lime, are the limestones. To a great extent they are of organic origin; that is, they have been formed from broken or pulverized animal relics, such as shells and corals; and in this case they are properly fragmental beds, although often so finely compact that this might not be suspected from their texture.

Some limestones have been made from the accumulation and consolidation of minute shells, called Rhizopods. These shells, which are generally no larger than grains of sand, are sometimes entire, but generally more or less broken. Chalk is an example of a rock made of Rhizopod shells.

Limestones made from fragments of earlier limestones occur, but are not very common. Limestone conglomerates are of this kind.

Other calcareous rocks have been deposited from waters holding the material in solution, and are, therefore, of chemical origin. Of this kind is the travertine of Tivoli near Rome in Italy, and of Gardiners River in the geyser region of the Yellowstone Park, and similar beds in many regions of mineral springs.

Siliceous Rocks. — Siliceous rocks are those that consist largely of silica in the form of quartz or (more rarely) opal. The name is from the Latin *silex*, signifying flint, a variety of quartz. Siliceous material, like the calcareous, is, as stated on page 19, of both mineral and organic origin; but the mineral is vastly the more abundant. It sometimes occurs as a chemical product, as in the siliceous depositions about geysers (page 187). The silica of chemical, as well as that of organic origin, is often in the state of opal. Opal, by solution and consolidation, may become converted into true quartz, as in flint, which has, for the most part, been made from the silica of Sponges.

The principal kinds of rocks are here described under the three heads: —

1, Fragmental Rocks, not calcareous; 2, Crystalline Rocks, not calcareous; 3, Calcareous Rocks.

1. FRAGMENTAL ROCKS, NOT CALCAREOUS.

The fragmental material which the wear and decomposition of rocks ordinarily produces is either: (1) gravel or shingle; (2) sand; (3) mud, earth, or clay.

1. **Gravel.** — The pebbles in a gravel are often so coarse as to be readily recognizable as fragments of various rocks. Each pebble may accordingly contain two or more minerals. When the disintegration of rocks proceeds to the point of pulverization, each grain is apt to consist entirely of a single mineral.

2. **Sand.** — Most sand consists chiefly of quartz; but in some sands many of the grains are of feldspar and mica. Some contain much clay, or are argillaceous (so named from *argilla*, clay); some are red or brownish yellow, owing to the presence of iron oxide, and are called ferruginous; some will effervesce slightly with acid, owing to the presence of some calcareous material. Beach sands often contain red grains of garnet; and commonly black grains of magnetite, which a magnet easily attracts.

3. **Mud, Earth, Clay.** — Mud and earth contain, besides grains of quartz, some pulverized feldspar, or else clay, with more or less of other minerals. The terms argillaceous, ferruginous, calcareous, are here applied as above; the calcareous grains are usually derived from the grinding up of shells. When black, the color is due to carbonaceous material derived from vegetable or animal decomposition. The name *soil* is applied especially to earth containing considerable quantities of such products of organic decomposition, whence its fertility is largely derived.

Common clay is a mixture of pure clay with grains of quartz, feldspar, and usually traces of hydrous iron oxide (limonite), or else iron carbonate. Owing to the iron, it burns red, making red brick — heat changing the iron mineral present to hematite (page 27). Occasionally, as in certain Milwaukee clays, the iron is in an iron silicate, so that the heat cannot oxidize it; and consequently the bricks it makes are not red. Clays free from iron are required for white pottery; and clays free from grains of feldspar, for making fire-brick, because the feldspar is fusible.

Pure clay, or *kaolin*, is white, and feels greasy. It is an aluminium silicate containing 14 per cent of water. It results from the decomposition of feldspar (pages 113, 116). It is used in making fine pottery and porcelain, and also in giving body to paper.

Rock flour is finely pulverized rock of any kind.

The consolidation of gravel, sand, and mud or clay, produces, respectively, conglomerate, sandstone, and shale.

4. **Conglomerate.** — Consolidated gravel. If the stones are rounded, the rock is often called a pudding-stone; if in the form of angular fragments, a breccia; if the pebbles are of quartz, a siliceous conglomerate, or, when very firmly consolidated, a grit; if of limestone, a calcareous conglomerate. The stones may be a foot or more in diameter, though usually much smaller.

5. **Sandstone.** — A rock made of sand. Common colors are red, gray, brown, white. If composed of quartz sand, it is a quartzose or siliceous sandstone; if of granite sand, a granitic sandstone; if fine, earthy or clayey, an argillaceous sandstone; if containing some calcium carbonate, a calcareous sandstone. It makes a durable building stone when firm, if not much absorbent of water when immersed in it, and if free from pyrite so as not to rust on exposure. The brownish red sandstone is often called freestone. The sandstone used for grindstones is even-grained and more or less friable.

6. **Shale.** — A rock resulting from the consolidation of clay or clayey earth or fine mud, and splitting readily into rather thin laminæ parallel to the planes of stratification (page 31). The colors are of all dull shades from gray to red and black. Carbonaceous shale is a blackish kind, yielding mineral oil. Alum shale is a shale which has become impregnated with alum through the decomposition of the pyrite it contains.

7. **Tufa.** — A volcanic sandstone, composed of volcanic sand or ashes (see page 175). The color is usually brownish, grayish, or reddish.

2. CRYSTALLINE ROCKS, NOT CALCAREOUS.

The most important of these rocks may be arranged conveniently in four groups according to their mineralogical composition.

1. Rocks consisting chiefly of Quartz (or Opal).

1. **Quartzite.** — A metamorphosed quartzose sandstone. It is usually a very hard rock. It may be distinguished from the accumulations of quartz in veins by its granular structure (as seen under a lens, or in thin sections under the microscope). Itacolumite, or flexible sandstone, is a laminated, porous quartzite containing minute scales of a hydrous mica, which render the rock somewhat flexible.

2. **Chert.** — An impure flint or hornstone occurring in beds or nodules in some stratified rocks.

3. **Siliceous Sinter.** — Deposits of silica from solution in water, most commonly formed by hot springs. The silica is usually opal, more rarely quartz. The sinter deposited by geysers (page 187) is often called geyserite.

2. ROCKS CONSISTING OF POTASH FELDSPAR, WITH OR WITHOUT QUARTZ, AND USUALLY WITH MICA OR HORNBLENDE.

1. **Granite.** — A rock consisting of quartz, feldspar, and mica, generally so coarsely crystalline that its ingredients are conspicuous to the naked eye. Color, usually light or dark gray, or flesh-red, the latter shade derived from a flesh-colored feldspar; the quartz, uncleavable and usually light grayish or smoky in color; the feldspar, white to flesh-red, and yielding smooth, shining surfaces by cleavage; the mica, white to black, and affording thin, flexible leaves by cleavage. Most granite is igneous, and exhibits most typically the characters of the plutonic rocks. Some granite appears to be metamorphic. Some granite appears to constitute true veins (page 198).

2. **Gneiss.** — Like granite in constitution, but having a schistose structure, owing to the arrangement of the minerals, the mica, especially, being in parallel planes; it has, therefore, a banded appearance on a surface of transverse fracture. If the color of the gneiss is dark gray, it is banded usually with black lines consisting largely of black mica. Along the micaceous planes it breaks rather easily into slabs, which are sometimes used for flagging. Gneiss has probably been formed in most cases by the metamorphism of argillaceous sandstones. But other gneisses have been formed from granites by pressure or shearing, by which the ingredients have been forced into a parallel arrangement.

3. **Mica Schist.** — Related to gneiss, but consisting more largely of mica, with usually less quartz and very much

less feldspar, and, in consequence of the mica, breaking into thin slabs. The slabs have a glistening surface. In regions of mica schist the dust of the roads is often full of shining particles of mica. Mica schist is generally a metamorphic rock, and the same is probably true of most of the schists.

4. **Hydromica Schist.** — A slaty, fine-grained mica schist, feeling somewhat greasy to the fingers. It used to be called talcose slate; but it contains a hydrous mica instead of talc.

5. **Slate, Argillite, Phyllite.** — The rocks included under these names form a transition between the shales and the hydromica schists, and may with about equal propriety be placed in either position in the classification, being the result of a very feeble metamorphism. The texture appears to the naked eye hardly crystalline. They are fine-grained rocks; and the kinds valued as roofing slates and drawing slates are hard, smooth, and not absorbent of water. The color is usually dark gray, passing into bluish, greenish, and reddish shades. In these rocks the slaty structure is most perfectly displayed. As already explained (page 31), the planes of slaty cleavage are independent of the planes of stratification, and are due to pressure (page 219).

Perfectly gradual transitions may be traced from granite to gneiss, from gneiss to mica schist, from mica schist to hydromica schist, from hydromica schist to slate, and from slate to shale.

6. **Hornblende Granite, Quartz Syenite.** — A rock resembling granite, but containing hornblende instead of mica. Intermediate kinds occur, in which both mica and hornblende are present. Generally plutonic, like true granite.

7. **Syenite.** — Like the preceding, but with little or no quartz. Plutonic.

8. **Syenite Gneiss, Hornblende Gneiss.** — Related to hornblende granite precisely as gneiss is related to granite.

9. **Hornblende Schist.** — Related to the preceding as mica schist is related to gneiss, the micaceous and hornblendic series showing a close parallelism. Generally a metamorphic rock. Sometimes formed by alteration of diorite or some such igneous rock.

10. **Felsite.** — A fine-grained, often porphyritic rock, consisting chiefly of orthoclase, containing no glass. When quartz is present in considerable quantity, it is called quartz felsite. Much of the so-called porphyry belongs here. The colors are various, grayish and reddish shades being common. An igneous rock.

11. **Rhyolite.** — Similar in composition to a quartz felsite, but showing under the microscope the presence of glass, indicating rapid cooling. It is one of the common kinds of lava.

12. **Trachyte.** — Consists, like felsite, chiefly of orthoclase, but differs from felsite in containing some glass. The feldspar is partly of a variety occurring in crystals of glassy luster, called sanidin. One of the most common lavas.

13. **Obsidian.** — A lava having substantially the chemical composition of a rhyolite or trachyte, but cooled so rapidly as to be almost entirely glassy.

3. Rocks consisting of a Soda-lime Feldspar, with Hornblende or Pyroxene.

1. **Diorite.** — Differs from syenite in containing a soda-lime feldspar (generally oligoclase) instead of orthoclase. Coarsely or finely crystalline, containing no glass. It is sometimes porphyritic, and the classical red porphyry of Egypt (*rosso antico*) is here included. Rather dark grayish and greenish colors predominate. It is generally an igneous rock, though it may be sometimes metamorphic.

2. **Andesite.** — Similar in composition to diorite, but partly glassy. A common kind of lava.

3. **Gabbro.** — A coarsely crystalline rock, consisting chiefly of a soda-lime feldspar (generally labradorite) and

pyroxene, often containing magnetite and chrysolite as accessory ingredients. In its coarseness of crystallization it resembles granite; and, like granite, is generally a plutonic rock.

4. **Dolerite, Diabase.** — Similar in composition to gabbro, but not so coarsely crystalline. Often porphyritic. Colors dark — black, shading into gray, greenish, or brownish colors. An igneous rock, very often occurring in dikes. This and other dark heavy igneous rocks are often called trap.

5. **Basalt.** — Similar in composition to gabbro and dolerite, but showing the typical volcanic character of containing glass. The rock (or the ground mass, when the rock is porphyritic) is so fine-grained as to appear compact to the naked eye. Color black, or nearly so. One of the most common kinds of lava.

6. **Tachylite.** — A lava substantially similar to basalt in chemical composition, but cooled so rapidly as to be almost entirely glassy.

4. Rocks consisting chiefly of Hydrous Magnesian Silicates.

1. **Chlorite Schist.** — A schistose rock of dark green color, consisting chiefly of chlorite. It is connected by intermediate gradations with hydromica schist.

2. **Talc Schist.** — A schistose rock of grayish or greenish color and greasy feel, consisting chiefly of talc. A comparatively rare rock, most of the rocks to which the name has been applied being hydromica schist.

3. **Steatite, Soapstone.** — Like talc schist, except in the lack of the schistose structure. The finer-grained varieties are used for slate pencils and for various other purposes.

4. **Serpentine.** — A rock consisting chiefly of the mineral serpentine. In most cases it results from the hydration of rocks consisting wholly or largely of anhydrous magnesian silicates. Rocks containing chrysolite are especially liable to undergo this alteration.

3. CALCAREOUS ROCKS.

1. Non-metamorphic.

1. **Common Limestone.** — A compact rock of grayish and other dull shades of color to black, consisting either of calcite or dolomite, but often impure from the presence of clayey or earthy material. It breaks with little or no luster. If containing fossils, it is called fossiliferous limestone; if the fossils are Corals, coral limestone; if remains of Crinoids, crinoidal limestone. When impure, and therefore good for making hydraulic lime (quicklime that will make a cement which sets under water), it is called hydraulic limestone. Chalk is a variety of limestone soft enough to be used for marking, and consisting chiefly of shells of Rhizopods.

Many varieties of common limestone are polished and used as marbles; they have black, reddish, yellow, gray, and other colors; kinds containing fossil shells are called shell marbles.

2. **Oölite.** — A limestone consisting of concretions as small as the eggs in the roe of fish, or smaller — whence the name, from the Greek *ᾠόν*, egg. Oölitic limestone occurs in all the geological formations, and is forming in modern seas about the Florida Keys and in other coral-reef regions.

3. **Stalactite, Stalagmite, Travertine.** — Stalactites are accumulations of limestone hanging from the roofs of caverns; and stalagmite is the same material covering the floors; both are formed from the calcareous waters that come through the roof, and are sometimes called dripstone. A similar deposit from streams or ponds is called travertine; it is sometimes used for a building stone.

4. **Marl.** — Clay containing much calcium carbonate, and hence used as a fertilizer. The term is used popularly for any rock material that can be so used. Shell marl consists largely of shells. Greensand marl is sand consisting largely of grains of a green silicate of iron and potash called glauconite.

2. Metamorphic.

Crystalline Limestone; Architectural and Statuary Marble.—Limestone having a crystalline texture, and, consequently, glistening on a surface of fracture. A pure, white kind, of fine grain, is used for statuary, and both this and coarser varieties for marble buildings. Many of the clouded marbles are here included.

II. ROCK MASSES, OR TERRANES.

The rocks above described are the material of which the great rock masses, or terranes, of the globe consist. These rock masses are either stratified or unstratified.

The Stratified Condition. — Stratified rocks are those which lie in beds or strata. The word *stratum* (the singular of *strata*) is from the Latin, and signifies that which is spread out.

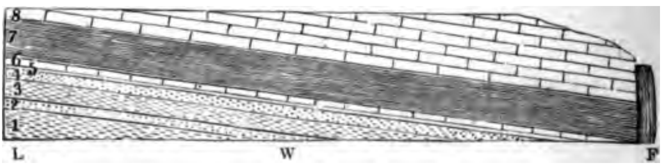
In geology, a stratum includes all the beds of one kind of rock (as of limestone, or of sandstone, or of any other kind) that lie in one continuous series.

The earth's rocky strata are spread out in beds of vast extent, many of them thousands of square miles in area and thousands of feet in thickness.

The stratified rocks exposed to view over the earth far exceed in area the unstratified. They are the rocks of nearly the whole of the United States and of almost all of North America, and not less of the other continents. Throughout central and western New York, and the states south and west, the rocks, wherever exposed, are seen to be made up of a series of beds. And, if the rocks are less distinctly stratified over most of New England, it is, in general, only because the structure has been partly obscured by the upturning and crystallization they have undergone since they were formed.

Fig. 13 represents a section of the rocks along the river below Niagara Falls. It gives some idea of the alternations which occur in the strata. In a total height of 250 feet (165 feet at the falls, at F, on the right) there are, on the left, six different strata in view, and parts of two others, the upper and lower, making eight in all. Number 1 is shale; 2, sandstone; 3, shale; 4, sandstone; 5, shale; 6, limestone; 7, shale; 8, limestone. Only two of these strata, 7 and 8, are in sight at the Falls (at F). The alternations are thus numerous and various in most regions of stratified rocks. Along the cañon of the Colorado, there are in some places more than 8000 feet of consecutive stratified beds, showing their edges in lofty precipices, and in the mountains towering above the adjoining plains. Fig. 14 represents one of the scenes along the cañon.

Fig. 18.



Section along the Niagara River.

It must not be inferred that the earth is covered by a regular series of coats, the same in all countries; for this is far from the truth. Many strata occur in New York that are not found in Ohio and the states west, and many in southern New York that are not found in the northern part. Moreover, a stratum of limestone may change in the course of a few miles to one of sandstone or shale.

A layer is one of the subdivisions of a stratum. A stratum may consist of an indefinite number of layers.

In many stratified rocks, as in most limestones, conglomerates, and the coarser sandstones, the strata or layers are thick, and the structure of the rock is massive (page 31). But argillaceous sandstones and shales generally split into thin layers, showing thus a laminated or shaly structure. Sometimes the rock shows on cross fracture a minutely banded appearance, due to variation in the color or texture of the deposit, even though the thin layers may not be separable. Such minutely banded rocks are said to be straticulate, whether the layers are separable or not.

FIG. 14.

Wall of Colorado Cañon.

A *system* includes all the various kinds of strata that were formed in one age or era, as the Carboniferous system, or that of the Coal. The term *series* is used like *system*, but with most writers it denotes a less extensive division. Subdivisions of a system or series are called *groups*; a subdivision of a group, a *stage*.[1]

[1] There is no uniformity of usage among geologists, in regard to the order of the terms defined in this paragraph.

The term *formation* is often used instead of *system* or *series*. But it is also employed to designate all the rocks of a kind making a continuous mass in a region, as a limestone formation, a coral formation, a granite formation.

Origin of Stratification. — The stratified structure is due to changes, at longer or shorter intervals, in the formations in progress over a region. For a long time limestones may have been forming. Then, through some change in the conditions — it may be a change of level, or of marine currents, — sandstones were formed over the limestone stratum. After another change, deposits of mud, or clay, or pebbles, succeeded. Such alternations have been going on in one part or another of the seas over the continental areas, through all geological time.

Changes, also, in kinds of species populating the seas have helped to mark the distinction in successive strata; though generally in connection with some physical or geographical change, as change of currents, or of temperature in the waters, or of their purity, or of level, increasing or diminishing the depth. According as such changes occur at long or short intervals, the beds consequently produced are of greater or less thickness.

In all cases, the subdivisions are due to changes of conditions; and, for the very thin layers of the straticulate structure, those changes may be the daily alternations or ebb and flow of the tides; or the changes of velocity in the blasts of wind over a region of sand; or the successive throws of the breakers over a beach; or simply wavelike vibrations in any body of water. For a wave has its time of maximum and minimum movement, and therefore its times of unequal force in the process of deposition, and waters of breakers descending a beach have their time of action succeeded by a time of rest.

In volcanic work, also, there are alternations. Outflows of lava are separated from one another by intervals of rest, or by times when only steam, other gases, and volcanic ashes are ejected.

Thus strata, beds, layers, from the coarsest stratification to the finest straticulation, have one general cause; and bedding is absent from deposits only when alternations did not occur during the deposition, or when the materials, as those of many conglomerates, are too coarse to admit of the finer bedding.

Unstratified Condition. — Unstratified rocks are those which do not lie in beds or strata. Mountain masses of granite are usually without any appearance of stratification. The rock of the Palisades, on the Hudson, stands up with a bold columnar front, and has no division into layers. Most volcanic formations exhibit a sort of stratification, due to the alternations mentioned above; though the name *stratification* is not usually applied technically to volcanic rocks. But in some volcanic regions the rocks rise into lofty summits without stratification. Veins (page 196), dikes (page 188), and other special modes of occurrence of unstratified rock will be described hereafter.

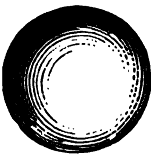
Relation of Stratified and Unstratified Rocks in the Earth's Crust. — The relations of the stratified and unstratified rocks in the earth's crust will be understood after considering the origin of the crust.

The unstratified rocks which once formed the surface of the globe were made by the solidification of the molten mass. After the solidifying of the sphere at surface, the ocean commenced at once to make fragmental stratified rocks over the exterior through the wear of those primitive unstratified rocks, and the stratifying of the sand or mud thus made. The ocean thus worked over and covered up with strata nearly all, if not all, the original unstratified crystalline rocks. Hence the areas of the unstratified rocks that were made in the first solidification of the globe, are of very small extent over the continents, if visible anywhere.

Geology has, for its study, chiefly stratified rocks. Much the larger part of all the facts in geological history are derived from rocks of this kind, and therefore the various details with regard to their structure and arrangement are of the highest importance.

Concretions. — Rocks often contain, and sometimes consist of, small spheres or disks of mineral matter, which are called concretions. Concretions result from a tendency in matter to concrete or solidify around centers. Some are no larger than grains of sand, or the eggs in the roe of fish, as in oölitic limestone (page 40). Others are as large as peas or bullets, and others a foot or more in diameter.

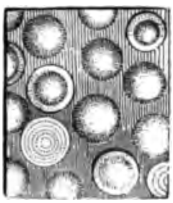
Fig. 15.



A spherical concretion.

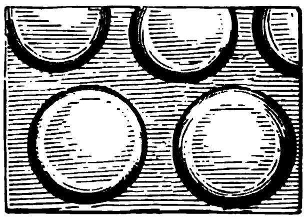
Fig. 15 represents a spherical concretion; Fig. 16, a rock made up of rounded concretions, having a concentric

Fig. 16.



Concretions with concentric structure.

Fig. 17.

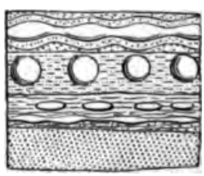


Disk-shaped concretions.

structure; Fig. 17, one with flattened or disk-shaped concretions.

Concretions are made by the deposit of calcium carbonate or some other material held in solution or suspension by waters percolating through the rock. They are usually spherical in massive sandstones, because solutions in such rocks spread equally in all directions; but lenticular in laminated rocks, and flattened disks in argillaceous rocks or shales, because in these rocks waters spread laterally more easily than vertically. All these kinds are shown in Fig. 18.

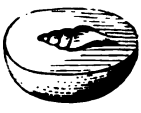
Fig. 18.



Strata containing concretions.

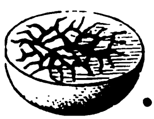
The balls are sometimes hollow, and the disks mere rings. Frequently the concretions have a shell or other organic object at center (Fig. 19). They are often cracked through the interior (Fig. 20) from drying (some soft clayey muds contracting to a tenth of their bulk); the outside in such a case solidified while the inside was still

Fig. 19.



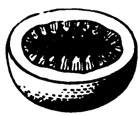
Concretion with a fossil at its center.

Fig. 20.



Concretion with shrinkage cracks.

Fig. 21.

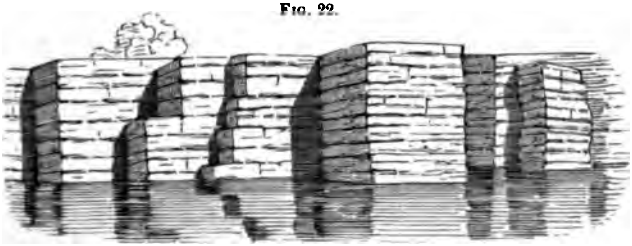


Geode.

moist. The cracks may afterward become filled with other minerals. Sometimes they contain a loose ball within— a concretion within a concretion. A cavity lined with crystals (Fig. 21) is called a geode; but the hollow balls so lined within are not generally concretions.

Joints. — The rocks of a region are often divided very regularly by numerous planes of fracture, the most of them

Fig. 22.



Jointed structure, shore of Cayuga Lake.

parallel to one another, and cutting through the strata, perpendicularly, or at various angles, to great depths, but with the walls of the fissures generally in contact or but slightly separated. Such deep unopened fractures may characterize the rocks over areas hundreds of miles in extent. They are called joints; and a rock thus divided is said to present a jointed structure. In many cases there are two systems of joints or divisional planes in the same region, crossing one another; and the undermining of a bluff of jointed beds and tumbling down of masses lead to the production of forms like those of fortifications or broken walls, as shown in Fig. 22, representing a view on the shores of Cayuga Lake. The directions of such joints are facts which the geologist notes down with care.

Slaty Cleavage. — The peculiar structure of slates and allied rocks (cleavage) has been referred to on page 31; and it has been stated that the planes of cleavage are usually not parallel to the bedding; that is, they cross the layers of stratification more or less obliquely, instead of conforming to the layers of bedding like the divisional planes in the shaly structure. Slaty cleavage is in this respect like the jointed structure; but it has the divisional planes so numerous that the rock divides into slates in-

FIG. 23.

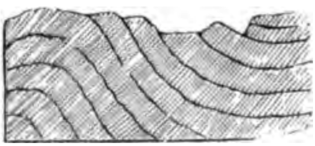
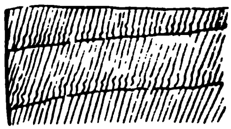


FIG. 24.



Slaty cleavage.

stead of blocks; and the two differ in mode of origin. Slaty cleavage is confined to fine-grained rocks. In Fig. 23, the lines of bedding or stratification are shown at *a*, *b*, *c*, *d*, while the transverse lines correspond to the direction of the cleavage. The same is shown in Fig. 24, with the addition of a slight irregularity in the slates along the junction of two layers.

POSITIONS OF STRATA.

1. **Original Position of Strata.** — *Horizontal Position.* — Ordinary stratified rocks were once beds of sand or earth, or of other rock material, spread out by the currents and waves of the ocean, or the waters of lakes or rivers, or by the winds.

[redacted]

When the larger portion of the beds over the North American continent were formed, the continent lay to a great extent beneath the ocean, as the bottom of a great, though mostly shallow, continental sea. The principal mountain chains — the Rocky Mountains and the Appalachians — had not been made, and the surface of the submerged land was nearly flat. That those beds were really marine, is proved by their containing, in most cases, marine shells, crinoids, or corals, the relics of marine life; and that the continental seas had great extent, is proved by the fact that the beds cover surfaces tens of thousands of square miles in area, some of them reaching from the Atlantic border westward beyond the Mississippi. In those large continental seas, the deposits made by means of the currents and waves were nearly or quite horizontal. Wherever they reached the surface, like the sand flats off many modern seashores, the sweep of the waters over them during the incoming tide would tend to plane off and keep level the upper surface of the beds, whether accumulations of sand or earth, or of shells or corals. If the bottom over the region were very slowly sinking, the accumulations might go on thickening, and the beds continue to have the same level or horizontal position. Strata formed along the borders of rivers and lakes are nearly horizontal, and so are those on the borders of the ocean; and for a like reason, that the water works with reference to its surface, which is horizontal. Moreover, the bottom of the border of the Atlantic, south of Long Island, for 80 miles from the coast line (see Fig. 3, page 13), deepens only 1 foot for every 600 to 700; and, if the area were above the ocean, no eye would detect that it was not a perfect level.

The view of the rocky wall of the Colorado Cañon, on page 43, illustrates well the approximate horizontality of the original bedding, and shows that it was continued through many long periods; for the series of rocks, more than 5000 feet thick, represents a long succession of geological formations.

Some beds were originally vast marshes, like the marshes of the present day, only larger. Such was the condition of the beds that are now coal in the Coal formation. Many coal beds contain stumps of trees rising out of the coal (Fig. 25); and they always stand perpendicularly to the bed, however much the latter may be displaced, showing that the bed was horizontal when it was formed, or when the trees were growing.

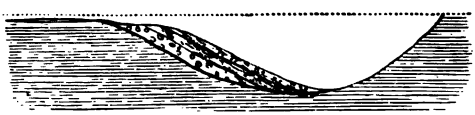
Exceptions to a Horizontal Position. — When a river empties into a lake or sea, the bottom of which, near its mouth, is more or less inclined, the deposits of detritus made by the river will for a while conform to the slope of the bottom, as in Fig. 26. When a river falls down a precipice, it makes a steep bank of earth at the foot, whose layers, if any are made, have the slope of the bank. In beach-made deposits the layers have the slope of the beach (page 154). But these and similar cases of exceptions to a horizontal position are of small extent.

FIG. 25.

Coal beds with fossil stumps.

2. **Dislocations of Strata.** — Most of the strata of the globe have lost their original horizontal position so as to be more or less inclined; and some are even vertical. They are occasionally bent or folded, as a quire of paper might be folded, only the folds are miles, or scores of miles, in sweep.

FIG. 26.



Inclined strata deposited on a steep slope.

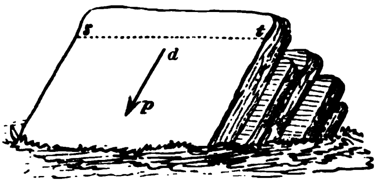
They have often also been fractured, and the separated parts have been pushed, or else have fallen, out of their former connections, so that the portion of a stratum on one side of a fracture is often inches, feet, or even miles, above that on the other side.

The maximum thickness of stratified rocks is said to be over 25 miles, though only a part of this thick-

[redacted]

ness exists in any one region (pages 42, 224). If the strata were all in their original horizontal position, it is evident that no such thickness of strata could be within the reach of observation. The maximum thickness of strata observable under such conditions would be limited by the height of cliffs formed by erosion, or by the depth of artificial borings. But the upturning which the earth's crust has undergone has brought the edges of strata to the surface, and there is hence no such limit: however deep stratified beds may extend, there is no reason why the whole should not be brought up so as to be exposed to view in some parts of the earth's surface.

FIG. 27.



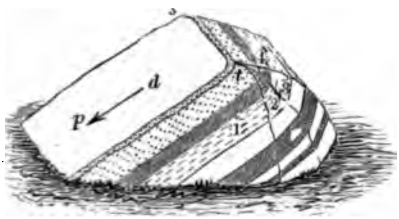
Outcrop.

The following are explanations of the terms used in describing the positions of strata: —

Outcrop. — The portions or ledges of strata projecting out of the ground, or in view at the surface (Fig. 27).

Dip. — The slope of inclined or tilted strata. In Figs. 27, 28, *dp* is the direction of the dip. Both the angle of slope (*i.e.*, the angle between the plane of stratification and a horizontal plane), and the direction with reference to points of compass, are noted by the geologist: thus, it may be said of beds, the dip is 50° to the south, or 5° to the northwest, etc.

FIG. 28.

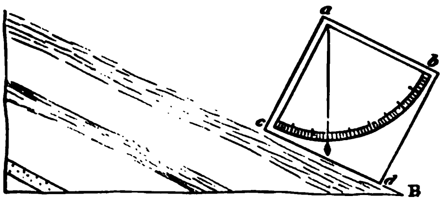


Sections showing true and false dips.

When only the edges of layers are exposed to view, it is not safe to take the slope of the edges as the slope of the layers; for, in Fig. 28, the edges on the faces 1, 2, 3, 4 are all edges of the same beds, and only those of the face 1 would give the right dip.

The dip is measured by means of instruments called clinometers. In Fig. 29, *abcd* represents a square block of wood, having a graduated arc *bc*, and a plummet hung below *a*. Placed on the sloping surface AB, the position of the plummet gives the angle of dip. This kind of clinometer is often made in the form of a watch, and combined with a compass. It is most convenient for use when it has a square base. One like that figured is easily made out of a piece of board; it may be 3 to 4 inches on a side, and about half an inch thick. To avoid errors from the unevenness of a rock, a board may be laid down first, and the measurement be made on its surface. But, if the instrument has a square base, it is often best to measure the dip by holding it between the eye and the rock, with one edge of the base in the direction of the dipping layers.

FIG. 29.

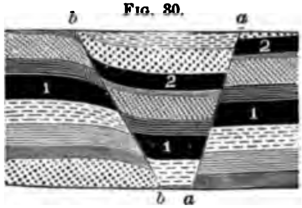


Measurement of dip, by clinometer.

Strike. — The horizontal direction at right angles with the dip. In Fig. 27, the dotted line *st* represents the direction of the strike. It is measured by means of a small compass, which usually forms part of the clinometer. Such a compass may be set in a clinometer made like the one shown in Fig. 29. It need not be central in the square, but should have the meridian line parallel to one of the four sides. If the edges of the layers in view over a ledge are in any part quite horizontal, the direction of those edges will give the true strike; but, if they are at all inclined, the direction of a horizontal line must be determined on the surface of one of the layers. The clinometer may be used also for measuring the dip of rocks that are rods distant, and the slopes of distant mountains.

Faults.—In the making of faults (*aa*, *bb*, Fig. 30), there is a fracturing, and a shoving up or down of the beds on one side of the fracture; that is, a downthrow on one side or an upthrow on the other. The amount of displacement is the amount of fault; it may be a foot or less, or 10,000 feet or more. The friction attending the movement may cause a bending of the layers in contact, as along the line *bb*, in Fig. 30. The deepest fractures and faults have been produced in connection with the making of mountains.

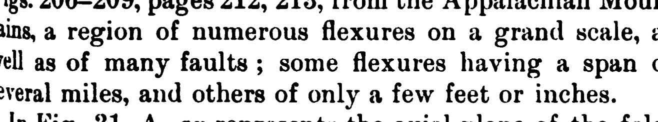
Fig. 30.



Faults.

Folds or *Flexures.* — Folds or flexures in strata are represented in Fig. 31, A, B; and in the natural sections

Fig. 31.

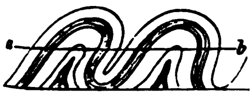


Anticlines and synclines.

Figs. 206–209, pages 212, 213, from the Appalachian Mountains, a region of numerous flexures on a grand scale, as well as of many faults; some flexures having a span of several miles, and others of only a few feet or inches.

In Fig. 31, A, *ax* represents the axial plane of the fold, and the intersection of the surface of the strata by that plane is the axis of the fold.

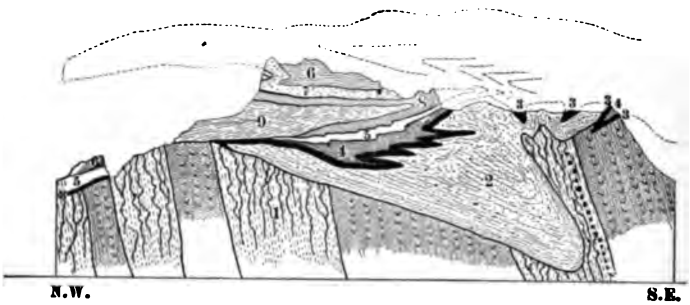
Fig. 32.



Overturned folds.

The flexure very often has one side steeper than the other, as illustrated above. In some regions, the push by which it was made was continued until the strata became vertical; and, further still, until the top was pressed over beyond the vertical, and fold of this kind followed fold, as illustrated in Fig. 32. In more extreme cases, the push was continued until there was produced a complete inversion of the beds, as is represented in Fig. 33, a section of the Dent de Morcles, near Martigny in Switzerland, by Golliez. The length of the section is about five miles; and the horizontal and the vertical scale of the figure are equal. The horizontal line at the base of the figure represents the level of the sea. The stratum 9, which before the folding was the uppermost stratum, is folded back on itself; and 8, 7, and 6, which were originally underlying strata, now overlie it, upside down. It is seen that the strata 6 and 7 are present only in the overturned part of the fold; these beds must have ex-

FIG. 33.



Section of the Dent de Morcles. — 1, Metamorphic rocks; 2, Carboniferous; 3, Triassic; 4, Lower Jurassic (Lias and Dogger); 5, Upper Jurassic (Malm); 6, Lower Cretaceous (Neocomian); 7, Upper Cretaceous; 8, Lower Eocene (Nummulitic); 9, Upper Eocene.

tended northwestward between 5 and 8, but they have been pinched out in the lower limb of the fold by the tremendous pressure to which the rocks have been subjected. At the extreme left of the figure, stratum 6 is seen in its normal position overlying 5.

Flexures often have fractures somewhere along the bend; and the fractures are often lines of fault.

Anticline.—An upward arching of the strata, which slope away from the axial plane in opposite directions, as the layers either side of *ax* in Fig. 31, A: the axis is here called an anticlinal axis. The word *anticline* is from the Greek ἀντί, in opposite directions, and κλίνω, to incline.

Syncline. — A downward bend, the strata sloping toward the axial plane. In Fig. 31, B, the axes corresponding to *ax*, *ax*, are anticlinal axes, that corresponding to *a′x′*, between the others, a synclinal axis. The word *syncline* is from the Greek σύν, together, and κλίνω.

Monocline. — A form of flexure in which the strata slope in only one direction, as when a series of strata is elevated (relatively) in one area and depressed in an adjacent area without fracture. Such monoclinal flexures pass by fine gradations into faults. A series of strata having an apparently monoclinal attitude may be only a part of an anticline or syncline of which the other side is concealed. The word *monocline* is from the Greek μόνος, one, and κλίνω.

Geanticline, Geosyncline. — Bendings of the earth's crust, *geanticline* an upward bend, and *geosyncline* a downward bend. These words are from the Greek γῆ, earth, and the words *anticline* and *syncline.*

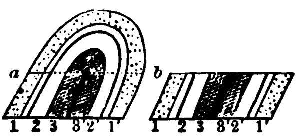
In ordinary synclines and anticlines, the flexures involve a varying thickness of strata, the arches have a span of a few miles at most, and the height of the arches bears generally a large ratio to the width. In geanticlines and geosynclines, the earth's crust is affected to a much greater depth (extending much below the stratified portion, or supercrust), the arches have a span of scores or hundreds of miles, and the height of the arches is very small in comparison with their width. Within the limits of a single geanticline or geosyncline, there may be a number of alternating anticlines and synclines.

The subject of flexures and faults is best studied by making models out of sheets of moist clay (or better of paraffin containing a little beeswax), using lampblack and red and yellow ocher for coloring the different beds, and then making cross sections.

Effects of Denudation on Flexed or Upturned Rocks;

Decapitated Folds. — If the top of the fold in Fig. 34 were cut off at *ab*, there would remain the part represented in Fig. 35, in which there is no appearance of any fold, and only a uniform series of dips; and, although 1′, 2′, 3′, appear to be the lower strata of the series, they are actually parts of 1, 2, 3. A long series of such folds pressed together, and then decapitated, would make a series of uniform dips (an apparently monoclinal structure) over a wide extent of country (see Fig. 32).

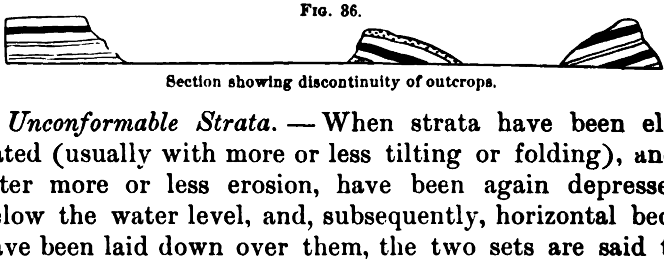
FIG. 34. FIG. 35.



Sections showing effect of decapitated folds.

The true succession has been further obscured by the removal of the beds over great areas and the filling up of intermediate depressions by soil; so that the rocks are visible only at long intervals (as in Fig. 36). Many of the difficulties in the study of rocks arise from this cause.

FIG. 36.

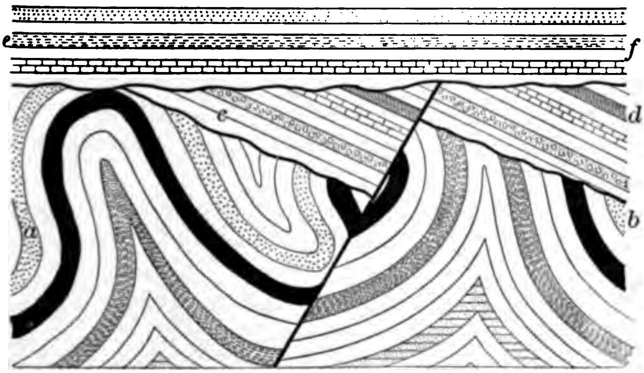

Section showing discontinuity of outcrops.

Unconformable Strata. — When strata have been elevated (usually with more or less tilting or folding), and, after more or less erosion, have been again depressed below the water level, and, subsequently, horizontal beds have been laid down over them, the two sets are said to be unconformable. Thus, in Fig. 37, the beds *ef* are unconformable both with the tilted beds *cd* and with the folded beds *ab*; so also the tilted beds *cd* are uncomformable with those beneath.

It is plain that the folded rocks *ab* are the oldest, and that the folding took place before the overlying beds were deposited. Again, it is evident that the beds *cd* are older than the beds *ef*, and also that they were tilted and faulted before the latter were formed. Supposing the uppermost of the folded rocks *ab* were of Carboniferous age, and the tilted beds *cd* were Triassic, the geologist would conclude that the upturning and folding of the earlier rocks occurred after the deposit of the Carboniferous strata and before that of the Triassic. In like manner, if the horizontal strata *ef* were Cretaceous, the time of the tilting and faulting of the beds *cd* would be shown to be between the Triassic and the Cretaceous.

The special significance of unconformability in the interpretation of the geological record, is that it always marks an interval of time during which (in the region in question) no rocks were formed. The two sets of strata may

FIG. 87.



Unconformable strata.

be richly fossiliferous, and so bear testimony in regard to the history of life in their respective periods. But, for the interval, long or short, in which the older series of strata was above the water level, and was undergoing erosion, there is, at least locally, a gap in the record.

Overlap is the name given to the condition which exists when the sea, after depositing a series of strata, has spread more widely over the land, and has deposited another series of beds with these new limits. These changes of sea level were going forward during the progress of most formations, and, consequently, overlap should be common, though not always easily distinguished.

THE ANIMAL AND VEGETABLE KINGDOMS.

SINCE life has been an important agent, dynamically, in Geology, and its history constitutes a chief part of the historical branch of the science, some knowledge of the various kinds of animals and plants is of the highest importance to the student. A brief review of the classification of the animal and vegetable kingdoms, and of the distribution of life over the globe, is here introduced.

CLASSIFICATION.

Distinctions between an Animal and a Plant. — A typical animal (1) is sustained by nutriment taken into its interior for digestion and assimilation. (2) It is capable of perceiving the existence of other objects, through one or more senses. (3) It has (except in some of the lower species) a head, in which are the principal nerve centers controlling voluntary motion, and the mouth. (4) It is fundamentally a fore-and-aft structure, the head being the anterior extremity; and it is typically forward-moving. (5) With its growth from the germ, there is an increase in mechanical power until the adult size is reached. (6) In the process of respiration, it uses oxygen and gives out carbonic acid. (7) It finds nutriment only in organic materials, or tissues of plants or animals; never in mineral material.

A plant (1) is sustained by nutriment taken into the tissues by absorption at the surface. (2) It is incapable of perception, having no senses. (3) It has no head, no power of voluntary motion, no mouth. (4) It is fundamentally an up-and-down structure, and, with few exceptions, fixed. (5) In its growth from the germ or seed, there is no increase of mechanical power. (6) In the process of nutrition, ordinary plants use carbonic acid, and give out oxygen with only an extremely small amount proportionally of carbonic acid. The Fungi, and some other plants that are not green, are an exception, using oxygen, and giving out much carbonic acid. (7) A plant finds nutriment in mineral material, from which it makes organic tissues.

The Animal Kingdom.

The nature of an animal requires, for a full exhibition of its powers, the following parts: —

1. A stomach and its appendages, to turn the food into blood, with an arrangement for carrying off refuse material.

2. A system of vessels for carrying this blood throughout the body, so as to promote growth and a renewal of the structure.

3. A heart, or forcing pump, to send the blood through the vessels.

4. A means of respiration, or of taking oxygen into the system (as by lungs or gills), since the energy of the body is derived from the combination of oxygen with the elements contained in the food.

5. Muscles, or contractile fibers, to put the parts or members in motion by their contraction.

6. A brain, or head mass of nervous matter, to serve as a seat of sensation and volition, and a system of nerves to convey sensory impressions to the brain and motor impulses to the muscles.

In the lowest forms of animal life, as some microscopic Protozoans, the stomach is not a permanent cavity, but is formed in the mass of the tissue whenever and wherever a particle of food comes in contact with the body. In other words, a stomach is extemporized as it is needed. Animals of a little higher grade, as Anthozoans, have mouth and a stomach, muscles, an imperfect nervous system, and a means of respiration through the general surface of the body; but there is no heart, and the animal is ordinarily fixed to a support.

The subkingdoms, or primary divisions of the animal kingdom, most commonly recognized at present by zoölogists, are the following: —

1, PROTOZOANS; 2, SPONGES; 3, CŒLENTERATES; 4, ECHINODERMS; 5, MOLLUSCOIDS; 6, MOLLUSKS; 7, VERMES, or WORMS; 8, ARTHROPODS; 9, TUNICATES; 10, VERTEBRATES.[1]

1. PROTOZOANS.

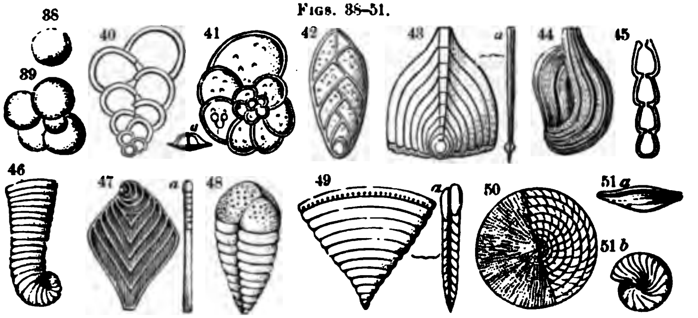
The name *Protozoans* is derived from Greek πρῶτος, first, and ζῶον, animal, and accordingly signifies the simplest and lowest of animals. According to the modern doctrine of evolution, some representatives of this group must have been the first of animals in time, and the ancestors of all more complex forms. The Protozoans are characterized by their extreme simplicity, the minute body consisting strictly of a single cell. The Protozoans that form communities by continuous budding or fission, and thus come to form masses of some size, constitute only an apparent exception to the above statement.

[1] This classification is provisionally adopted as a matter of convenience, since it is believed to be used more generally than any other in recent manuals of zoölogy, though it does not precisely express the views of the editor. In former editions of this work, the Sponges were included among the Protozoans; the Cœlenterates and Echinoderms were united under the name Radiates; the Molluscoids, Mollusks, and Tunicates were united under the name Mollusks; and the Vermes and Arthropods were united under the name Articulates. In the latest edition of the Manual, the Cœlenterates and Echinoderms are united under the name Radiates; the Molluscoids, Mollusks, and (doubtfully) a part of the Vermes are united under the name Non-Articulates; and the remainder of the Vermes and the Arthropods are united under the name Articulates.

[redacted]

There is in these creatures nothing like the development of the higher animals, in which the egg (originally a

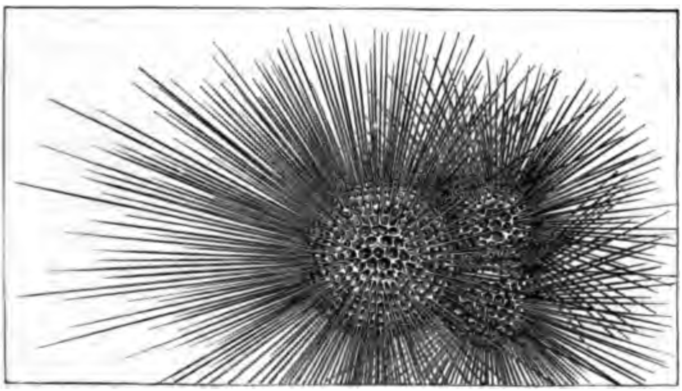
Figs. 38–51.



Foraminifers: Fig. 38, Orbulina universa; 39, Globigerina rubra; 40, Textularia globulosa; 41, Rotalia globulosa; 41 *a*, side view of Rotalia Boucana; 42, Grammostomum phyllodes; 43, *a*, Frondicularia annularis; 44, Triloculina Josephina; 45, Nodosaria vulgaris; 46, Lituola nautiloides; 47, *a*, Flabellina rugosa; 48, Chrysalidina gradata; 49, *a*, Cuneolina pavonia; 50, Nummulites nummularia; 51 *a*, *b*, Fusulina cylindrica.

single cell, like a Protozoan) comes to be divided into numerous cells, of which the various tissues of the body

Fig. 52.



Foraminifer: Globigerina bulloides.

are formed. Some of these minute creatures form calcareous or siliceous skeletons, and are therefore capable of preservation as fossils.

Of the classes of Protozoans, only one is of any importance in Geology, — the *Rhizopods.*

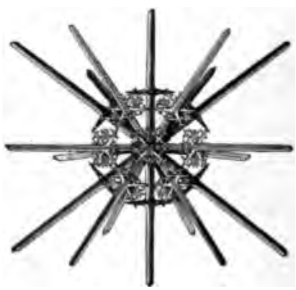
Rhizopods. — The name is derived from the Greek ῥίζα, root, and πούς, foot, and refers to the power which the animal possesses of protruding the jelly-like protoplasm of which the body is composed, into temporary processes, often slender and branching like little roots. These temporary extensions of the body, called pseudopods (Greek ψευδής, false, and πούς, foot), envelop particles of food, and serve as extemporaneous stomachs for its digestion. The power of extending the protoplasm of the body in various directions enables the creature to move with a sort of flowing movement.

Fig. 53.

Foraminifer: Rotalia, with pseudopods protruded.

Two groups of Rhizopods are especially important in Geology, — the *Foraminifers* and the *Radiolarians.* The *Foraminifers* (Latin *foramen*, in allusion to the minute pores in the shell through which the pseudopods are protruded) have generally calcareous shells. A number of the shells are represented in Figs. 38–51. Figs. 50, 51 are of natural size, and a few Foraminifers have shells even larger than these. The others are magnified, most of the shells being no larger than grains of sand. Fig. 52 represents (much enlarged) the common species of *Globigerina*, which lives at the surface of the ocean over wide areas, and whose dead shells accumulate in the ooze at the bottom. As shown in the figure, the shell, when alive or unbroken, is covered with radiating

Fig. 54.

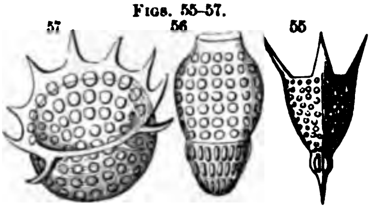


Radiolarian: Xiphacantha, x 50.

spines. Fig. 53 represents another living species (also much enlarged), showing the pseudopods extended.

The *Radiolarians* (Latin *radius*, in allusion to the radiated arrangement of the pseudopods) are somewhat more highly organized than the Foraminifers, the protoplasm of their bodies showing more indication of differentiation into parts. They have siliceous skeletons, which are often exquisitely beautiful. Some of them are represented, considerably magnified, in Figs. 54–57.

FIGS. 55–57.

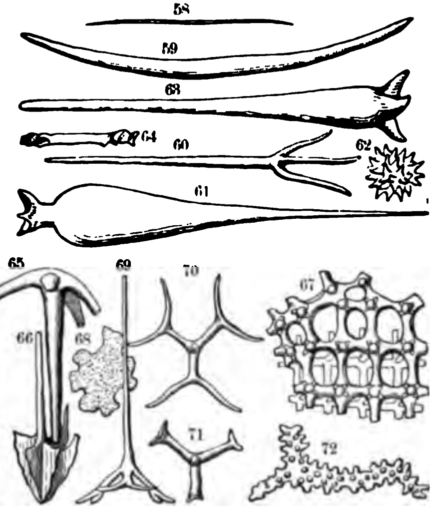


RADIOLARIANS: Fig. 55, Lychnocanium; 56, Eucyrtidium; 57, Halicalyptra.

2. SPONGES.

The Sponges show a higher grade of organization than the Protozoans, since they produce true eggs, which divide into numerous cells in the process of development. They attain, however, no such degree of differentiation of tissues and organs as is shown in the higher animals. The gelatinous body of a sponge is traversed by a system of canals, to which the sea water is

FIGS. 58–72.



SPONGE SPICULES: Figs. 58–61, Geodia or allied genera; 62, globostellate spicule, related to Geodia; 63, Stelletta; 64, Carterella; 65, 66, Tetractinellid spicules; 67, Ventriculites; 68, Ragadinia annulata; 69, Tisiphonia; 70, the same; 71, Racodiscula; 72, Plinthosella squamosa. Figs. 62, 65, 66, × 10; 68, × 68; others, × 34. Hinde.

admitted by numerous minute pores, and from which it is discharged through a smaller number of larger orifices. In most Sponges the gelatinous body is supported by a network of horny fibers, generally associated with minute spicules of silica. The sponges used in bathing are the horny skeletons of species which are destitute of siliceous spicules. In some Sponges the skeleton is entirely composed of siliceous spicules, and still others have a calcareous skeleton. The spicules of Sponges have various forms, as shown in Figs. 58–72.

3. CŒLENTERATES.

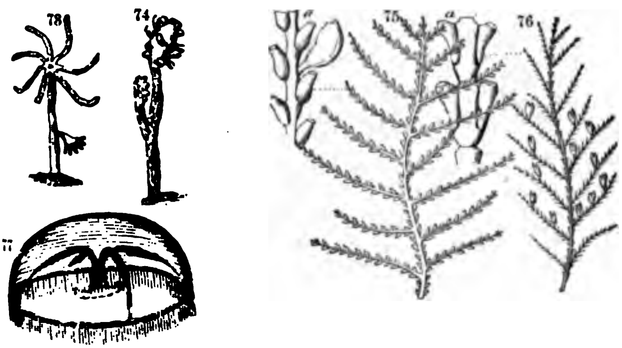
The name is derived from κοῖλος, hollow, and ἔντερον, intestine, and refers to the fact that in these animals the only cavity is the digestive cavity, there being no body-cavity, or perivisceral cavity, such as is found in the higher animals. By the possession of a distinct mouth and digestive cavity, the Cœlenterates show a higher grade than the preceding groups. Rudiments also of a nervous system appear. The mouth is generally surrounded by a wreath of radiating tentacles, and in most species all the organs are repeated in radial order.

Two of the classes of Cœlenterates are important in geology,—1, *Hydrozoans;* 2, *Anthozoans.*

1. **Hydrozoans.**—The name (from Greek, ὕδρα, hydra, and ζῷον, animal) denotes animals resembling the little fresh-water hydra. In that little creature (Fig. 73) the body is little more than a tube, with the opening of the mouth at one end, surrounded by a wreath of tentacles. Fig. 74 represents a somewhat similar marine form. In many cases communities are formed by budding, the successively formed individuals (zooids) remaining permanently attached to each other. These communities are often branching, and look like delicate seaweeds. They are often inclosed in a delicate horny investment. Two of these horny skeletons are shown in Figs. 75, 76. A few

(as Millepore) form a calcareous skeleton or coral. Other Hydrozoans, called Jellyfishes, or Medusæ, have the gelatinous body disk-shaped or hemispherical, and swim freely with the mouth downward. A Medusa is shown in Fig. 77. In many species, Medusæ are produced by budding from a colony of hydra-like zooids. In this case the Medusa produces eggs, from which the Hydroid community is developed. This alternation of generations is very common among Hydrozoans, and occurs in some other classes of animals.

FIGS. 73–77.



HYDROZOANS: Fig. 73, Hydra, × 8; 74, Syncoryne; 75, Sertularia abietina; *a*, same, magnified; 76, Sertularia rosacea; *a*, same, magnified; 77, Tiaropsis.

2. **Anthozoans.**—The name (from Greek *ἄνθος*, flower, and *ζῷον*, animal) refers to the beautiful flower-like aspect given to many of these creatures by their tentacles, which radiate like the petals of a flower (Figs. 78, 79, 81), and which are often brightly colored. Anthozoans are distinguished from Hydrozoans by having an involution of the body wall at the mouth, forming a short esophagus leading into the main cavity or stomach; and by having the latter cavity partly divided into radiating chambers by partitions extending inward from the body wall. Most of the Anthozoans form communities, branching (Fig. 79), incrusting, or massive (Fig. 80), by budding or

fission. Some Anthozoans, as the Sea Anemone (Fig. 78), have no hard parts. Most of them, however, form corals by the deposit of calcareous material in some part of the body wall, and in radiating plates (septa) extending into the radiating chambers. These radiating plates cause a coral to be marked by stars (one corresponding to each zooid in the community), as shown in Fig. 80, which represents a piece of fossil coral. Most of the coral animals belong to the group of *Zoantharians*, in which the tentacles and other radiating parts are indefinite in number

FIGS. 78–81.

ANTHOZOANS: Fig. 78, Actinia; 79, Dendrophyllia; 80, Isastræa oblonga; 81, Gorgonia.

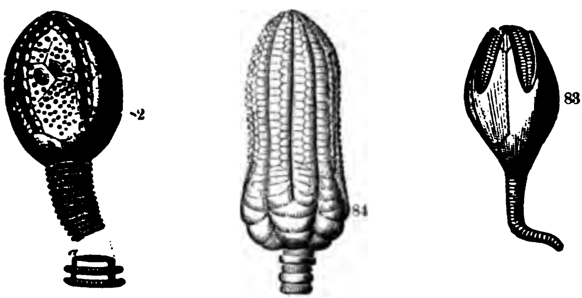
(Figs. 78, 79), and usually in multiples of six. In the remarkable fossil group of *Cyathophylloids*, the parts were in multiples of four. The Precious Coral and the Sea Fans (*Gorgonians*), with their peculiar horny skeletons, belong to the *Alcyoniarians*, in which the tentacles (Fig. 81) are uniformly eight in number and pinnate in form.

4. ECHINODERMS.

The name is derived from Greek ἐχῖνος, hedgehog, and δέρμα, skin, and refers to the armor of spines with which many of the species are covered (Fig. 87). The Echinoderms differ from the Cœlenterates in having a distinct body-cavity, or perivisceral cavity, within which the alimentary canal is contained. They show also a nervous system much more highly developed, consisting of a nervous ring around the mouth and radiating nerves passing to the several segments of the body. As in the Cœlenterates, the organs of the body in general are radially repeated. The number of radial segments is generally five. In some Echinoderms, the radial segments are very unequally developed, and the radial symmetry gives place in large degree to a bilateral symmetry.

Four of the classes of Echinoderms have considerably developed external skeletons, and are important in Geology: — 1, *Crinoids;* 2, *Ophiuroids;* 3, *Asterioids;* 4, *Echinoids.*

FIGS. 82–84.



CRINOIDS: Fig. 82, Callocystites Jewettii; 83, Pentremites pyriformis; 84, Encrinus liliiformis.

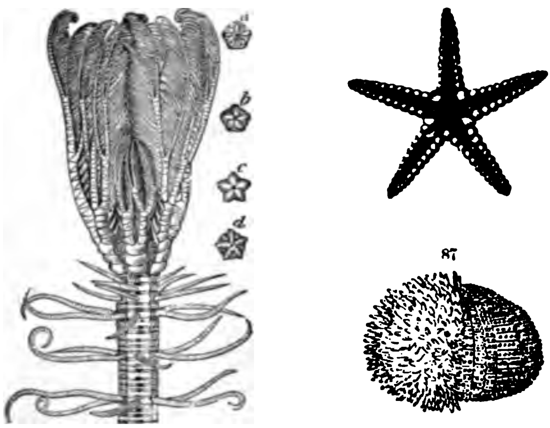
1. **Crinoids.** — The name is from Greek *κρίνον*, lily, and many of the species have been commonly called Stone-lilies. The species shown in Fig. 84 is named the Lily Encrinite. Unlike all other Echinoderms, they are (with perhaps a few exceptions) attached, at least temporarily, by a stem of greater or less length growing out from the pole of the body opposite the mouth. The Crinoids are a class almost extinct. One of the few living species is represented in Fig. 85. Two of the three orders of the class (Cystoids and Blastoids) are entirely extinct.

The *Cystoids* have the plates of the shell not regularly radial in arrangement, and the arms either altogether wanting or feebly developed, and not regularly radiating. One species is represented in Fig. 82.

The *Blastoids* (Greek βλαστός, bud) have an aspect of which the name is beautifully descriptive. The plates of the shell are arranged in regularly radial order. The arms are wanting, but are represented by five areas radiating from the oral pole of the shell, and bearing pinnules like those which are borne on the arms in the Brachiates. Fig. 83 represents a Blastoid.

FIGS. 85–87.

85 86 87



CRINOIDS: Fig. 85, Pentacrinus caput-medusæ; *a*, *b*, *c*, *d*, sections of stems of different species of Pentacrinus. — ASTEROID: Fig. 86, Palæaster Niagarensis. — ECHINOID: Fig. 87, Echinus, × ½.

The *Brachiates* (Latin *brachium*, arm) have the plates of the shell and the well-developed arms arranged in regularly radial order. The arms are typically five in number, but generally fork almost at the base, and often branch repeatedly, so as to seem very numerous. Two species are shown in Figs. 84, 85.

2. **Ophiuroids.** — The name (Greek ὄφις, snake, and οὐρά, tail) refers to the slenderness and flexibility of the rays which radiate from the small central disk. *Brittle Stars* and *Serpent Stars* are common names of these

animals. The viscera do not extend into the slender rays.

3. **Asterioids.** — The scientific name (Greek ἀστήρ, star) is descriptive of the form of the body, like the common name *Starfish.* A fossil species is shown in Fig. 86. The rays, or arms, blend with the central disk, instead of being sharply distinguished from it, as in the Ophiuroids; and the appendages of the alimentary canal and the other viscera extend into the rays.

4. **Echinoids.**—The name (from Greek ἐχῖνος, hedgehog) refers to the spines, which in some species are large and conspicuous. In Fig. 87 they are shown on the left side, having been removed from the other side to show the arrangement of the plates of which the shell is composed. In most of the Echinoids, the plates are immovably articulated with each other, so as to form a rigid shell. In this they differ from the preceding classes, in which the plates (at least in the rays) are movably articulated. The Echinoids are usually spheroidal or discoidal in form. They are commonly called Sea Urchins.

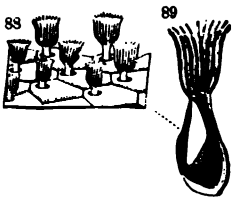
5. MOLLUSCOIDS.

The name implies a resemblance to the Mollusks, with which the Molluscoids were formerly confounded. The two groups agree in the absence of the radial repetition of homologous parts, which is characteristic of the two preceding subkingdoms, and in the absence of the longitudinal repetition of homologous parts, which is characteristic of many Vermes and of the Arthropods and Vertebrates. The Molluscoids differ from the Mollusks in having a much less strongly developed nervous system; in not having particular parts of the body specialized for locomotive and sensory functions (foot and head), as is the case in most of the Mollusks; and in being generally attached, while the Mollusks are generally locomotive. Eminently characteristic of the Molluscoids is a sort of collar about the mouth (lophophore), sometimes nearly circular, sometimes horseshoe-shaped, sometimes produced into a pair of long arms, bearing a fringe of tentacles or cirri.

The Molluscoids include two classes, both of which are important in geology: — 1, *Bryozoans*; 2, *Brachiopods*.

1. **Bryozoans.** — The name (Greek *βρύον*, moss, and *ζῷον*, animal) is prettily descriptive of the delicate mosslike tufts which are formed by many of the communities of these little creatures. They multiply by budding (as well as by producing eggs), and the communities thus formed often greatly resemble those of Hydrozoans. The animals, however, are much higher in their grade of organization, possessing an alimentary canal inclosed in a perivisceral cavity, and a well-developed nervous ganglion. The lophophore (well shown in Figs. 88, 89) is circular or horseshoe-shaped, bears a wreath of relatively long tentacles, and is never produced into a pair of long arms. The Bryozoan communities are sometimes destitute of any hard parts, but generally secrete a horny or calcareous covering, which incloses each zooid in a little cell. When the skeleton is calcareous, it forms a delicate sort of coral.

FIGS. 88, 89.



BRYOZOAN: Eschara; Fig. 88, part of a community, slightly enlarged; 89, single zooid, removed from its cell, more enlarged.

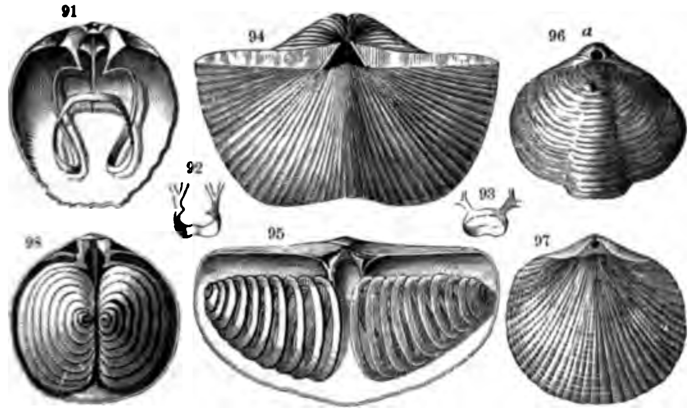
2. **Brachiopods.** — The name (from Greek *βραχίων*, arm, and *πούς*, foot) refers to the peculiar development of the lophophore, which in these animals is produced into a pair of long fringed arms, which are spirally coiled within the shell. In Fig. 90, one of the arms is extended beyond the margin of the shell. Unlike the Bryozoans, the Brachiopods never multiply by budding. The skin is produced into two folds, one on the dorsal, and one on the ventral side of the body, which secrete the two pieces of a bivalve shell. Brachiopods were formerly confounded with the Lamellibranchs among the Mollusks (Clams, Mussels, etc.),

since these animals also have bivalve shells. The valves in the Lamellibranchs are right and left, and are therefore entirely different from those of Brachiopods in their relation to the body of the animal. This difference of position is correlated with characteristic differences in the form of the shell. In Brachiopods the two valves are never alike, while in Lamellibranchs (with a few exceptions, as the Oyster) they are nearly or exactly alike. On the other hand, each valve is almost always symmetrical in the Brachiopods, never in Lamellibranchs. The shells of a number of Brachiopods are shown in Figs. 91–98. In many Brachiopods, processes are developed from the interior of the dorsal valve, to

Fig. 90.

Brachiopod: Rhynchonella psittacea.

Figs. 91–98.



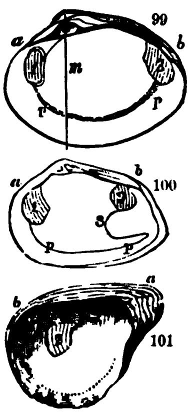
Brachiopods: Fig. 91, Waldheimia flavescens, interior view; 92, loop of Terebratula vitrea; 93, loop of Terebratulina caput-serpentis; 94, Spirifer striatus; 95, same, interior of dorsal valve; 96, Athyris concentrica; 97, Atrypa reticularis; 98, same, interior of ventral valve.

support the arms of the lophophore. These arm-supports may be looplike (Figs. 91–93) or spiral (Figs. 95, 98). The Brachiopods are generally attached by a fleshy stem passing out between the valves, or (more commonly) through an aperture in the beak of the ventral valve (shown at *a* in Fig. 96). In one recent species of *Lingula*, the pedicel has been observed to serve as an organ of locomotion. The Brachiopods are represented by but few living species, but were immensely abundant in early geological periods.

6. MOLLUSKS.

Mollusks agree with the Molluscoids in the absence of segmentation, either radial or longitudinal. They show, however, a much higher grade of organization. Almost always there is a foot, or specialized locomotive portion of the body; and generally a head, or specialized oral and sensory portion. The nervous system is well developed. Special respiratory organs are generally present, most commonly in the form of gills. Budding is entirely unknown, reproduction being solely by means of eggs. The integument is generally produced into a fold, or a pair of folds, called the mantle, which secretes a calcareous shell. The shell is generally large enough to form a covering for the body; but is sometimes small and concealed in the mantle, and sometimes rudimentary or wanting.

FIGS. 99–101.



LAMELLIBRANCHS: Fig. 99, Cyprina; 100, Tellina; 101, Ostrea.

Of the classes of Mollusks, three are important in Geology:—1, *Lamellibranchs;* 2, *Gastropods;* 3, *Cephalopods.*

1. **Lamellibranchs.**—The name (from Latin *lamella* and *branchia*) refers to the form of the gills, which in most species are developed as two lamellar folds on each side of the body. The Lamellibranchs differ from the other classes to be described, in the lack of a distinct head, and in the lack of any masticatory apparatus connected with the

mouth. The mantle is always developed in two lobes (right and left), and the shell accordingly is always bivalve. The distinctions between the shells of the Lamellibranchs and those of the Brachiopods have been given on page 71. The interior of the shell in Lamellibranchs bears markings which give much information in regard to the soft parts of the body. The shell is generally closed by two powerful muscles, the anterior and the posterior adductor. These make deep impressions where they are inserted into the shell (1, 2, in Figs. 99, 100). Sometimes (as in the Oyster) the anterior adductor is wanting, and then only one impression is shown in the shell (2, in Fig. 101). In most shells a somewhat distinct line extends from one adductor to the other (*pp*, in Figs. 99, 100), formed where the muscular border of the mantle adheres to the shell. In some species, the mantle lobes are entirely separate along the ventral margin, admitting the water freely to the gill chamber. In others, the mantle lobes are united along the ventral margin, and their posterior border is produced into two tubes (siphons) by which, respectively, water is admitted and expelled. These siphons are generally more or less perfectly retractile; and the mantle impression shows a notch, or sinus (*s*, in Fig. 100), marking the area into which the siphons are withdrawn. These markings are often clearly shown in fossil shells.

2. **Gastropods.** — The name (from γαστήρ, belly, and πούς, foot) refers to the fact that these animals generally crawl on the ventral surface of the flattened foot, as well shown in Fig. 102, representing a land Snail. The head is supplied typically with two pairs of sensory tentacles, one of which bears a pair of eyes. In the Snail (Fig. 102) the eyes are borne on the larger posterior tentacles. The two pairs of tentacles may be more or less perfectly fused into a single pair. Respiration is generally effected by means of gills; but in the land Snails there is an air sack, or simple lung; and some Gastropods have no special organs of respiration. The great majority of the Gastro-

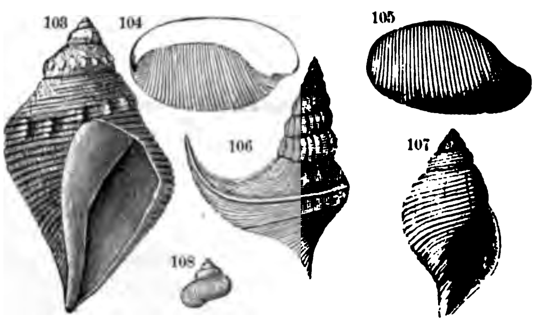
pods have shells in the form of a turreted spiral, enough to cover the animal completely. A numb fossil species are shov Figs. 103–108. Others shells flattened, conical, other forms. The shell be small and concealed i mantle, or may be en: wanting.

Fig. 102.

Gastropod: Helix.

In the *Pteropods* ((πτερόν, wing, and πούς, foot), regarded by most zoöl(as an aberrant group of Gastropods, though pe: deserving to be considered as a distinct class, a pa

Figs. 103–108.



Gastropods: Fig. 103, Pyrifusus Newberryi; 104, 105, Bulla speciosa; 106, ((Drepanochellus) Americana; 107, Fasciolaria buccinoides; 108, Margarita Nebras

lateral appendages to the foot are developed as fins (sl in Fig. 109). Unlike most Mollusks, these little tures are adapted for a free-swimming, pelagic life. At present, the Pteropods include only a small number of species, all of which are of very small size. In early geological times much larger species existed.

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3. **Cephalopods.**—The name is from Greek κεφαλή, head, and πούς, foot. In these most highly organized of Mollusks, the head is armed wi

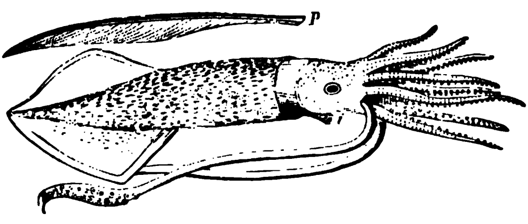
circle of prehensile tentacles, and bears two large eyes of remarkably elaborate structure. Respiration is always by means of gills. The water taken into the gill chamber is expelled through a funnel (shown at *i* in Fig. 111). The reaction of the water, when forcibly ejected, propels the body in the opposite direction, affording one of the means of locomotion possessed by these active creatures. The Cephalopods are divided into two orders, both of which have played an important rôle in geological history.

FIG. 110.

TETRABRANCH: Nautilus.

The *Tetrabranchs* (Greek *τέτρα*, four, and *βράγχια*, gills) have four gills. Their tentacles are numerous, but not armed with suckers or hooks. They have no ink-bag. They are defended by

FIG. 111.



DIBRANCH: Loligo vulgaris, × ¼; *i*, funnel; *p*, pen.

an external shell in the form of a tube, which may be straight or coiled, but which is always divided into chambers by transverse partitions (septa), which are perforated by a smaller tube (siphuncle). Fig. 110 shows in section the coiled and chambered shell of *Nautilus*, the only living genus of the order.

The *Dibranchs* (Greek *δίς*, twice, and *βράγχια*, gills) have two gills. Their tentacles are eight or ten in number, and bear suckers or hooks, making them very powerful weapons.

They secrete an inky fluid, which is discharged through the funnel when they seek to escape from pursuers. With an apparent exception in a single genus, they have no external shell. They generally, however, have some sort of a shell concealed in the mantle. This may be the horny pen of the Squid (*p*, in Fig. 111), the so-called bone of the Cuttlefish, or a chambered shell resembling the shells of the Tetrabranchs.

7. VERMES, OR WORMS.

The animals commonly included under this name are a heterogeneous group. Some of them have the body divided into a longitudinal series of segments, and the nervous system constructed on the same plan as that of the Arthropods, with which the Segmented Worms are probably closely related. Others (including the numerous parasitic Worms) are not segmented. The only skeletal structures possessed by any Worms are minute jaws, which are occasionally preserved as fossils. Otherwise, they are indicated in the rocks only by trails left on the mud and by remains of the tubes and burrows in which they have lived. The whole subkingdom is unimportant to the geologist.

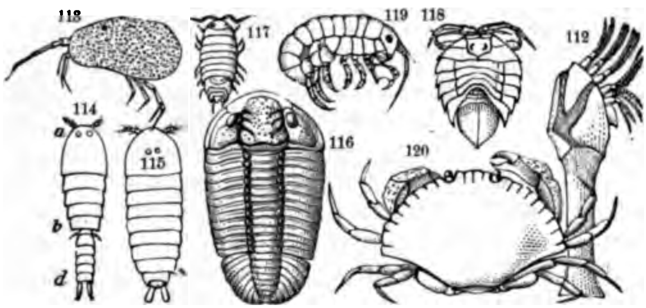
8. ARTHROPODS.

The name is derived from the Greek ἄρθρον, joint, and πούς, foot, and refers to the jointed appendages, or limbs, which are so conspicuous in the Lobster and in most Insects. The body is composed of a longitudinal series of joints or segments, well shown in the posterior part of a Lobster. The segmented structure is often obscured (especially in the anterior part of the body) by a number of the segments being fused together, as in the anterior part of a Lobster. Typically, each segment of the body bears a pair of jointed appendages, which may be antennæ (or feelers), jaws, accessory mouth organs, legs for walking or swimming, etc. The nervous system consists typically of a pair of ganglions in each segment, connected by a double nervous cord along the ventral side of the body, though in many cases the ganglions of several segments come to be united.

Four of the classes of Arthropods are important in Geology: — 1, *Crustaceans;* 2, *Merostomes;* 3, *Arachnoids;* 4, *Insects.*

1. **Crustaceans.** — The name (from Latin *crusta*, crust or shell) refers to the fact that the integument is generally hardened by a deposit of calcium carbonate, so as to

FIGS. 112–120.



ENTOMOSTRACANS: Fig. 112, Anatifa; 113, Cythere Americana; 114, Sapphirina iris, female; 115, same, male, × 6; 116, Calymene Blumenbachii. — MALACOSTRACANS: Fig. 117, Porcellio; 118, Serolis, × ½; 119, Orchestia; 120, Cancer.

form a sort of shell. The Crustaceans are aquatic Arthropods, breathing by means of gills (or through the integument, without special organs of respiration), and having typically the two anterior pairs of appendages developed as antennæ.

The Crustaceans are divided into two subclasses, the *Entomostracans* and the *Malacostracans.* In the former, the number of segments of the body varies widely, and very rarely more than three pairs of appendages serve as jaws or other mouth organs. In the latter subclass the number of segments of the body never varies far from the typical number (19)[1], and almost always four to six pairs of appendages function as mouth organs.

Among the *Entomostracans*, the *Trilobites*, named from Greek τρία, three, and λοβός, lobe, in allusion to the division of the body longitudinally into three lobes, as shown in Fig. 116, are an order now extinct, but immensely abundant in earlier geological periods. The Trilobites appear to represent a very primitive type of Crustacea, and they perhaps deserve to rank as a distinct subclass. In the *Ostracoids* (Fig. 113), the integument is produced into a pair of folds, right and left, forming a bivalve carapace, which reminds one of the bivalve shell of a Lamellibranch. The name is from the Greek ὄστρακον, shell. The *Cirripeds*, or Barnacles (Fig. 112), attach themselves by means of modified antennæ, and become covered by a hard shell of several pieces, looking somewhat like the shell of a Mollusk.

Among the *Malacostracans* is included the curious group of the *Leptostracans*, which are in many respects intermediate between the typical Malacostracans and the Entomostracans. The Leptostracans are now nearly extinct, though they seem to have been represented in earlier times by numerous species, some of them being of large size. One of them is shown in Fig. 233, on page 249. The *Arthrostracans*, or *Tetradecapods* (Greek τέτρα, four, δέκα, ten, πούς, foot), have four pairs of appendages developed as mouth organs, and seven pairs as legs. Here belong the Sow-bugs and Sand-fleas. Three species are shown in Figs. 117–119. The highest order of the Malacostracans is that of *Decapods* (Greek δέκα, ten, and πούς, foot), in which six pairs of appendages are developed as mouth organs, and only five pairs as legs. Here belong the Lobster and the Crab (Fig. 120), the former representing the suborder of *Macrurans* (Greek μακρός, long, and οὐρά, tail),

[1] Exclusive of the telson, at the posterior extremity of the body, which, though it never bears appendages, is considered by many zoölogists a true segment.

the latter representing the suborder of ***Brachyurans*** (Greek βραχύς, short, and οὐρά, tail).

2. **Merostomes.**—The name is derived from the Greek μηρός, thigh, and στόμα, mouth, and refers to the fact that some of the appendages have their basal joints developed as jaws and their terminal portions developed as legs. The Merostomes differ from the Crustaceans in the absence of antennæ. The ***Limulus***, or Horseshoe Crab, is the only living genus of this class. In early geological times the class was represented by the ***Eurypterids***, one of which is shown in Fig. 278, page 271.

3. **Arachnoids.**—The name is from the Greek ἀράχνη, spider, and the Spiders and Scorpions are typical members of the class. They are terrestrial Arthropods, breathing by means of air sacks (lungs) or ramifying air tubes (tracheæ). They have no antennæ, two pairs of mouth organs, and four pairs of legs. The absence of antennæ, as well as certain other characters, has been held by many zoölogists to indicate a close relationship to the Merostomes.

4. **Insects.** — Terrestrial Arthropods, breathing by means of tracheæ. They have one pair of antennæ, three pairs of mouth organs, and (in the typical subclass) three pairs of legs. The Insects are divided into two subclasses, —***Myriopods*** and ***Hexapods***. The ***Myriopods*** (Greek μυρίος, countless, and πούς, foot) have numerous legs, the series of legs extending to the posterior extremity of the body. They have no wings. The ***Hexapods*** (Greek ἕξ, six, and πούς, foot) have three pairs of legs, borne on the three segments of the body (thorax) next behind the head. Most of them have two pairs of wings; but the Flies and their allies (***Dipters***) have only one pair, and some Hexapods are entirely wingless.

9. TUNICATES.

The Tunicates have no skeletons, and are unknown in fossil condition. They appear to be a degenerate branch of the Vertebrate stem. In adapting themselves to a sedentary life, they have lost most of the characteristics of Vertebrates, though their relation to that group is indicated by their embryology.

10. VERTEBRATES.

The Vertebrates, or vertebrated animals, take their name from the backbone, or vertebral column. The distinctive character of the Vertebrates is the division of the body into a dorsal cavity containing the central organs of the nervous system, and a ventral cavity containing the nutritive viscera, separated from each other by an axial skeleton. In the lowest Vertebrates, as in the embryos of the higher forms, this axial skeleton appears as an unsegmented chord (notochord). But, in all except the lowest Vertebrates, cartilaginous or bony rings are developed in the sheath of the notochord, which encroach upon it, often to its entire obliteration, forming the bodies of the vertebræ. Cartilaginous or bony arches connected with the vertebral bodies come to inclose more or less completely the nervous cord on the dorsal side of the axis and the viscera on the ventral side of the axis. The axial skeleton and the nervous cord both undergo remarkable modifications at the anterior extremity of the body, forming the skull and brain.

Vertebrates are divided into the following classes: — 1, *Leptocardians;* 2, *Marsipobranchs;* 3, *Fishes;* 4, *Amphibians;* 5, *Reptiles;* 6, *Birds;* 7, *Mammals.*

1. **Leptocardians.** — The name (Greek λεπτός, thin, and καρδία, heart) refers to the absence of a massive, muscular heart, the blood being propelled only by the action of muscular tissue diffused through various parts of the arterial system. The notochord shows itself in very primitive condition. There are no bones, scales, teeth, limbs, skull, nor brain. Having no hard parts, these animals have never been preserved as fossils. They are, however, profoundly interesting, since they represent, more nearly than any other animals, what must have been

the primitive type of Vertebrates. The class is represented only by the *Amphioxus*, or Lancelet.

2. **Marsipobranchs.** — The name (Greek *μάρσιπος*, pouch, and *βράγχια*, gills) refers to the form of the gills, which are a series of pouches on each side, communicating with the pharynx. The Marsipobranchs show a persistent notochord, with no vertebral bodies. They have no limbs, and the mouth is not provided with jaws. The Lampreys are familiar examples of this class. Their only hard parts are little teeth inserted in the mucous membrane of the mouth. Such teeth might be preserved as fossils, but have not yet been recognized.

3. **Fishes.** — These differ from the preceding classes in the development of cartilaginous or bony vertebral bodies, and in the possession of jaws and (generally) two pairs of limbs. They differ from the remaining classes in that the limbs are developed as fins, the respiration is by gills, and the heart consists (except in one subclass) of one auricle and one ventricle. The teeth, fin spines, scales, and bones of Fishes are among the important fossils in many formations.

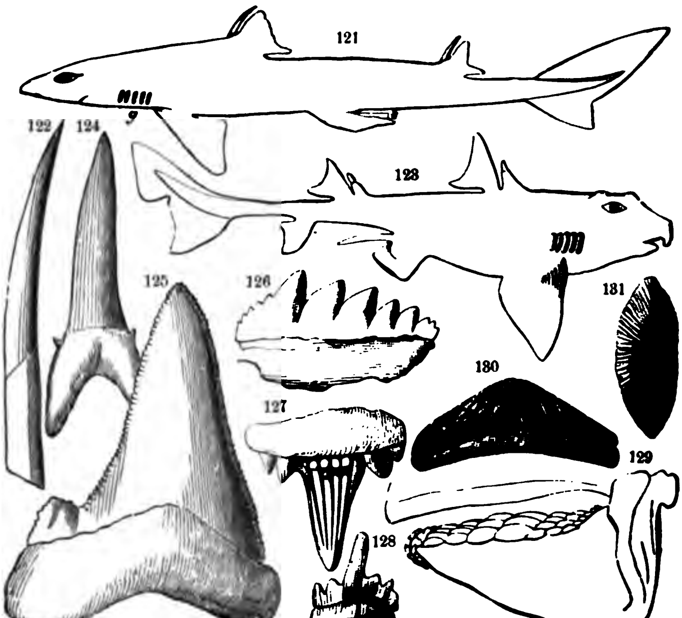
Fishes are divided into five subclasses: — 1, *Selachians*; 2, *Placoderms*; 3, *Ganoids*; 4, *Teleosts*; 5, *Dipnoans*.

The *Selachians* (Greek *σελάχη*, cartilaginous fishes) have skeletons but slightly ossified. The vertebral column extends to the extremity of the tail fin, generally bending up into the upper lobe, which is then commonly much longer than the lower, as shown in Figs. 121, 123. Such tails are called heterocercal (Greek *ἕτερος*, other, and *κέρκος*, tail). In some Selachians, however, the vertebral column extends in a straight line to the extremity of a symmetrical tail fin. This form of tail, called diphycercal, is believed to be the primitive type.

Many Selachians have strong spines at the margin of some of the fins (Figs. 121–123). They all have a skin roughened by minute toothlike points (shagreen). Some of them have sharp cutting teeth, as shown in Figs. 124–

126; others have flat pavement teeth, adapted to crush the shells of Mollusks and Crustaceans (Figs. 129–131). Figs. 127, 128, represent a somewhat intermediate type. The gills of Selachians are developed as a series of pouches through which the water passes from the pharynx

FIGS. 121–131.



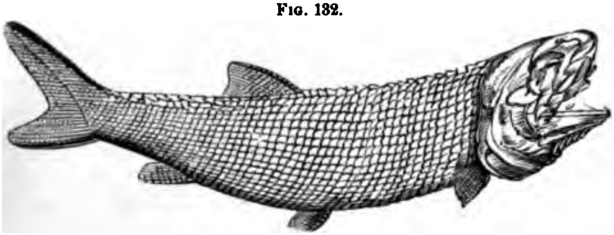
SELACHIANS: Fig. 121, Spinax Blainvillii, × [illegible]; 122, spine of anterior dorsal fin, natural size; 123, Cestracion Philippi, × [illegible]; 124, tooth of Lamna elegans; 125, Carcharodon angustidens; 126, Notidanus primigenius; 127, Hybodus minor; 128, Hybodus plicatilis; 129, lower jaw of Cestracion, showing pavement teeth; 130, tooth of Acrodus minimus; 131, Acrodus nobilis.

to escape by holes in the sides of the neck. The arrangement resembles that in the Marsipobranchs. In most Fishes the gills are developed as fringes projecting freely from the branchial arches of the skull. Most of the Selachians are commonly known as Sharks and Rays.

The *Placoderms* (Greek πλάξ, plate, δέρμα, skin) have the body, or at least its anterior part, covered with an armor of large, bony plates. Some of them are represented in Figs. 297–300, on page 285. As these creatures are known only as fossils, their true nature is somewhat doubtful. Some of them (Figs. 297, 298) appear to have no lower jaw, or at least none capable of preservation in a fossil state ; and it is doubtful whether they are truly Fishes. Others (Figs. 299, 300) have a well-developed lower jaw, and are believed by many paleontologists to be an aberrant group of Dipnoans.

The *Ganoids* (Greek γάνος, luster) are generally covered by hard, lustrous, enameled scales, most commonly of

FIG. 132.



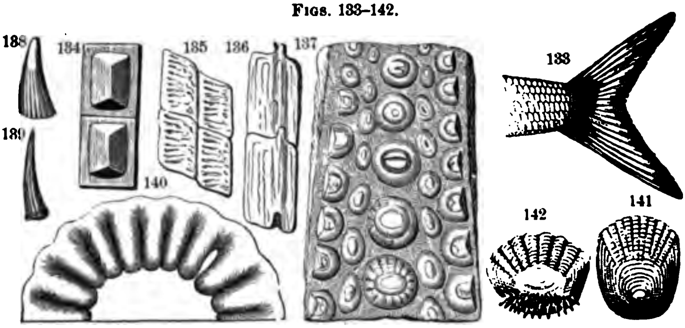
GANOID : Palæoniscus Freieslebeni, × ½.

rhombic form (Figs. 132–136). Some Ganoids, however, are clothed with cycloid scales (Fig. 141) like those of many Teleosts, from which they differ only in certain anatomical details relating to the optic nerves, the heart, and the intestine. The skeleton in the Ganoids varies greatly in the degree of ossification, sometimes becoming as perfectly ossified as in the Teleosts. The tail is sometimes heterocercal (Fig. 132) or diphycercal. In other Ganoids the vertebral column stops at or near the base of the tail fin, whose lobes then appear nearly symmetrical (Fig. 133). Such tails are called homocercal (Greek ὁμός, the same, and κέρκος, tail). The Ganoids are a group now nearly extinct, though very abundant in early geological times.

Teleosts (Greek τέλεος, perfect, and ὀστέον, bone) are so named on account of the high degree of ossification of their skeletons. With few exceptions, they are clothed with thin, membranous scales, which are called cycloid (Greek κύκλος, circle) when the posterior margin is smoothly rounded (Fig. 141), and ctenoid (Greek κτείς, comb) when the margin is beset with teeth (Fig. 142). Teleosts, with very few exceptions, have homocercal tails. The great mass of familiar Fishes belong to this subclass.

Dipnoans resemble the Ganoids in many respects, but have the air bladder developed into a functional lung, the auricle of the heart divided into two, and a distinct pul-

FIGS. 133–142.



GANOIDS: Fig. 133, tail of Aspidorhynchus; 134, scales of Cheirolepis Traillii, × 12; 135, Palæoniscus lepidurus, × 6; 136, inner surface of same; 137, pavement teeth of Gyrodus umbilicus; 138, tooth of Cricodus; 139, Lepidosteus osseus; 140, section of same, enlarged. — TELEOSTS: 141, cycloid scale; 142, ctenoid scale.

monary circulation. In these characters they show a transition to the Amphibians. They also differ from most Fishes, and agree with the higher classes of Vertebrates, in the mode of articulation of the jaws with the skull. The name is from the Greek δίς, twice, and πνέω, to breathe, in allusion to their possessing both gills and lungs.

4. **Amphibians.** — The name (Greek ἀμφί, on both sides, βίος, life) refers to the fact that most of these animals are partly aquatic and partly terrestrial in habit. Most of them undergo a strongly marked metamorphosis. In

their early stage, they breathe by means of gills, have a heart with a single auricle, and are aquatic; in adult life, they breathe by means of lungs, have two auricles and a distinct pulmonary circulation, and are more or less completely terrestrial. Their limbs (rarely wanting) are developed not as fins, but as legs. Toads, Frogs, and Salamanders are well-known examples of this class. The remarkable extinct group of the *Stegocephala*, or *Labyrinthodonts*, is illustrated on pages 308, 352.

5. **Reptiles.** — These resemble adult Amphibians in having a heart with two auricles and one ventricle (the Crocodiles being exceptional among recent Reptiles in having the ventricle divided), and in breathing by means of lungs. No gills are developed at any stage of life. *Turtles*, *Lizards*, *Snakes*, and *Crocodiles* are the principal groups of living Reptiles. The remarkable order *Rhynchocephala* is referred to and illustrated on pages 308, 309. That order is nearly extinct, being represented by a single genus in New Zealand. Numerous orders of Reptiles are entirely extinct, the present representatives of the class being only a remnant. Some of these fossil groups are described on pages 340, 352, 372.

6. **Birds.** — These differ from Reptiles in having a covering of feathers, and also in having two ventricles and a perfect double circulation. The more vigorous circulation and respiration cause Birds (like Mammals) to have a temperature often considerably above that of the surrounding medium. Birds and Mammals are accordingly said to be warm-blooded, while the preceding classes are said to be cold-blooded. The class of Birds is at present remarkably distinct and homogeneous; but some of the fossil birds (pages 356, 374) show characters which ally them very closely with Reptiles.

7. **Mammals.** — The name (from Latin *mamma*, breast) refers to the habit of suckling the young, by which these animals are characterized.

The subclass *Monotremes* are the lowest and most reptilian of Mammals. Like most Reptiles, they are oviparous; and in many points of their anatomy they greatly resemble Reptiles. They are now represented only by the Duckbill (*Ornithorhynchus*) and the Spiny Ant-eater (*Echidna*), both of which live in Australasia.

In the subclass ***Marsupials*** (Latin *marsupium*, pouch), the young are produced viviparously; but, in the absence of a placenta, the development is not far advanced before birth. The young are accordingly, in most species, carried by the mother for a time in a pouch formed by folds of skin, within which the teats are situated. With the exception of the Opossums, which live in America, the Marsupials are now confined to Australasia, where they are represented by Kangaroos, Phalangers, Wombats, etc. Formerly they existed in all regions of the globe.

In the ***Placentals***, or typical Mammals, provision is made for the nutrition of the embryo before birth, by means of the structure called the placenta; and the young are accordingly born in a more advanced stage of development. In this subclass are included all the familiar Mammals (with the exceptions above indicated), as well as Man himself.

The Vegetable Kingdom.

Plants are commonly divided into the two groups, *Cryptogams* and *Phanerogams*.

1. CRYPTOGAMS.[1]

The name (from Greek κρυπτός, secret, and γάμος, marriage) was given to these plants by Linnæus, in allusion to the fact that the reproductive organs appeared

[1] The group of Cryptogams is retained simply as a matter of convenience. It is a heterogeneous assemblage, like the assemblage of Invertebrates among animals. But the lower plants play so unimportant a rôle in Geology, that it is not worth while to trouble the beginner in Geology with the technicalities of the modern classification.

in general less conspicuous than in the Phanerogams, and that in many of them the reproductive processes were in his time altogether unknown. Here are included all plants which do not bear flowers and produce seeds. The reproductive bodies are single cells, and are called spores.

1. **Thallophytes.**[1] — This name is given to an assemblage of the lower Cryptogams, most of which agree in the negative character of showing no definite axis of upward growth, and no distinction of root, stem, and leaf. They all consist entirely of cellular tissue, being destitute of wood. These plants and the Bryophytes are sometimes called Cellular Cryptogams, in distinction from the Pteridophytes, which are called Vascular Cryptogams. The lowest Thallophytes are unicellular organisms. Some of the higher Thallophytes are large and complex plants.

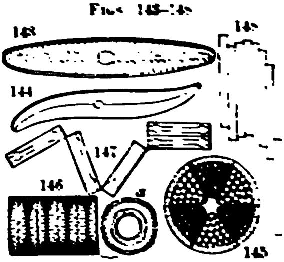
Disregarding the differences of structure of which a truly natural classification must take note, we may conveniently, for present purposes, divide the Thallophytes into two groups, on the basis of a single physiological character. Some of them contain chlorophyll, and are therefore capable of decomposing carbon dioxide and nourishing themselves upon inorganic materials. These are called *Algæ*. Most of these are aquatic, and many of them are popularly called Seaweeds. Other Thallophytes are destitute of chlorophyll, and must feed on organic materials. Some of them live as parasites upon other plants or upon animals; others live upon decaying organic matters. These are called *Fungi*. Mushrooms, Toadstools, Molds, Bacteria, etc., are here included. The Lichens, which often appear as grayish crusts on rocks and trees (often mistakenly called Mosses), appear to be composite organisms, consisting of an Alga and a Fungus.

Of these soft, woodless plants, only the aquatic Algæ attain any importance as fossils.

[1] This group, like that of Cryptogams, is heterogeneous, and is here adopted simply as a matter of convenience.

Diatoms are unicellular Algæ which secrete siliceous skeletons. They abound in both salt and fresh water, and their remains often accumulate so as to form deposits of considerable thickness. Several species are represented in Figs. 143–148. An interesting group of fossil Diatoms is shown in Fig. 140, on page 392.

FIGS. 143–148



DIATOMS, highly magnified: Fig. 143, Pinnularia peregrina; 144, Pleurosigma angulatum; 145, Actinoptychus senarius; 146, a, Melosira sulcata; 147, Grammatophora marina; 148, Bacillaria paradoxa

Desmids are unicellular Algæ, somewhat resembling Diatoms, but destitute of any siliceous skeleton. They are sometimes found fossil in flint and chert.

Corallines and *Nullipores* are Algæ which contain in their tissues a large amount of calcium carbonate.

The *Fucoids* include many large species of Algæ whose fronds have a leathery consistency. Casts of these are found fossil in many strata.

2. **Bryophytes.** — The name is from Greek *βρύον*, moss, and *φυτόν*, plant. The plants here included are the Liverworts and Mosses. In the Mosses, the habit of growth resembles that of the higher plants in the development of an axis of upward growth, forming a leafy stem. The Bryophytes, however, agree with the Thallophytes in being destitute of wood. A woodless terrestrial plant has little chance of preservation in fossil condition, and the Bryophytes are unimportant to the geologist.

3. **Pteridophytes, or Acrogens.** — The former name is from Greek *πτέρις*, fern, and *φυτόν*, plant; and the plants here included are the *Ferns*, *Equiseta*, and *Lycopods*. In these plants, as in the Phanerogams, the stems are strengthened by bundles of woody fiber. Such plants are much less perishable than the cellular plants, and accordingly are much more important in Geology. In the *Ferns* of temperate climates the stems are mostly underground, so

that the fronds spring from the ground; but in some tropical Tree Ferns the fronds spring from the summit of a trunk fifty feet or more in height. The *Equiseta* of the present time (often called Horsetails, or Scouring Rushes) are slender plants with hollow, jointed stems. The *Lycopods* are often called Club Mosses, or Ground Pines. All living species of Equiseta and Lycopods are small plants, rising only a few inches above the ground. In former geological times, both groups were represented by large trees.

2. PHANEROGAMS, OR PHÆNOGAMS.

Both names (one from Greek φανερός, manifest, and γάμος, marriage; the other from φαίνω, to appear, and γάμος) refer to the fact that the reproductive organs are conspicuous, and the reproductive processes have long been well known. The essential reproductive organs are the stamens and pistils; and these, with the floral envelopes, which are generally present and often conspicuously colored, constitute the flowers. The pistils bear the ovules, which develop into seeds. A seed contains an embryo plant already formed. In most Phanerogams, as in the higher Cryptogams, there is a definite axis of upward growth, and a distinct differentiation of root, stem, and leaves; and in all Phanerogams, as in the Pteridophytes, more or less of wood is developed. In the arrangement of the wood cells and ducts (fibrovascular bundles) Phanerogams exhibit two distinct types. In *exogenous* stems (Greek ἔξω, outward, γένω, to grow), the fibrovascular bundles are arranged in a hollow cylinder around a central pith. If the stem continues to grow for successive years, each season of growth adds a layer of wood between the outermost of the previous layers and the bark. A transverse section of such a stem (Fig. 149) shows a series of rings corresponding to the successive seasons of growth. In *endogenous* stems (Greek ἔνδον, within, and γένω), the fibrovascular bundles are distributed through the stem without any definite arrangement in concentric zones (see Fig. 150).

Phanerogams are divided into two classes, — *Gymnosperms* and *Angiosperms*.[1]

1. **Gymnosperms.** — The name (from Greek γυμνός naked, and σπέρμα, seed) refers to the fact that the seed are not enveloped in a closed case, or ovary. In the Pine and other Conifers, the pistil is simply a scale upon whos surface the ovules are borne. The dense clusters of ver simple flowers form th so-called cones in thes plants. The mode o growth of the Gymnosperms is exogenous The wood consists al most exclusively of single kind of cells showing under the microscope peculiar mark ings (disks), which ar really pits in the wal of the cell (see Figs 151, 152). This structure may be recognized even i petrified wood of Gymnosperms. In one group of th Conifers, the *Araucariæ*, the disks are arranged alter nately (Fig. 152), and fossils of that group have bee recognized by that character.

Figs. 149–152.

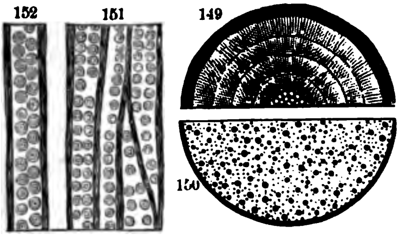


Fig. 149, section of exogenous stem; 150, same of endogenous; 151, wood cells of the Conifer, Pinus strobus, showing disks magnified 300 times; 152, same of Araucaria Cunninghami.

The two principal orders of Gymnosperms are the *Conifers* (Pines, Spruces, Cedars, etc.) and the *Cycads* (ofte mistakenly called Sago Palms).

2. **Angiosperms.** — The name (from Greek ἀγγεῖον vessel, and σπέρμα, seed) refers to the fact that the pisti forms a closed case, or ovary, in which the ovules an

[1] In the Manual of Geology, and in the previous editions of this work the Phanerogams are divided into Exogens and Endogens. Exogens ar equivalent to Gymnosperms and Dicotyledons, and Endogens to Monocotyledons, of the present classification.

seeds are developed. The wood is more complex in its structure than in the Gymnosperms, consisting in part of very slender, thick-walled cells (the ordinary wood cells), and in part of cells of somewhat larger diameter (ducts), with a variety of microscopic markings due to the thickening of parts of the cell wall.

The Angiosperms are divided into two subclasses, — *Monocotyledons* and *Dicotyledons.*

In *Monocotyledons*, the embryo in the seed bears only a single leaf (cotyledon), and the growth is endogenous.[1] The leaves are generally parallel-veined. Palms, Grasses, Lilies, and Orchids are examples of this subclass.

In *Dicotyledons*, the embryo in the seed bears a pair of opposite leaves (cotyledons), and the growth is exogenous. The leaves are generally net-veined. To this group belong the great majority of the trees and shrubs of our forests and of the herbs of our fields and gardens.

GEOGRAPHICAL DISTRIBUTION OF MARINE LIFE.

Range of Life in Depth. — Recent investigations have shown that living species not only inhabit the border regions of the oceans, but also extend widely and abundantly over a large part of the ocean's depths. Fishes, Crabs and other Crustaceans, Worms, Echini, Starfishes, Crinoids, Corals, are abundant to depths of 10,000 to 13,000 feet, and some of them to 18,000 feet. Crustaceans of large size, allied to Shrimps, many of them with good eyes, have been found at all depths to 2900 fathoms; and large Crabs, with perfect eyes, at 1700 fathoms. Some species have a very wide range in depth; one Coral

[1] The correlation of monocotyledonous embryos with endogenous stems, and of dicotyledonous embryos with exogenous stems, holds good in general, yet in some members of each group there are instances of stems which fail more or less completely to show the typical character.

(a disk-shaped kind, *Bathyactis symmetrica*) occurs (state Moseley) at depths from 30 to 2900 fathoms.

Character of the Sea Bottom. — The material most widely diffused over the ocean's bottom is a fine red or gray mud or clay. But over vast regions less than 15,000 feet in depth occurs the Globigerina ooze. At these and greater depths occur areas of Diatom ooze, especially in the Antarctic seas, in a zone between 50° and 70° south latitude; and areas of Radiolarian ooze, especially in tropical and warm-temperate regions.

The character of the bottom shows that sediments from the rivers of the continents are not carried far out to sea. Stones of a pound weight, and larger, occur 100 miles southeast of Long Island; but these are supposed by Verrill to have been carried out by shore ice. Clay, with some fine quartz sand and particles of mica, makes up the gray mud; and the winds may be a principal source of the sand and mica. Pumice and fine materials of volcanic origin are also widely distributed, indicating that the driftings by the wind from volcanic islands have been to great distances and over very large areas. The reddish color of much of the oceanic clay is attributed to the oxidation of the iron in volcanic cinders. Grains and nodules of oxide of manganese are very common over the ocean's bottom.

The bottom is the receiving place of all the dead remains of the ocean's life, both plant and animal, exclusive of the very large part that does not have a chance to reach the bottom, because of the eaters. In the Challenger expedition, in the South Pacific, the trawl brought up, at one haul, more than 1500 Sharks' teeth and fragments (not counting very small fragments) and about 50 ear bones of Cetaceans. Among the Sharks' teeth found in that region, many are believed to be of Eocene age; and their being buried not more than a foot, although lying there since the early Tertiary, is regarded as evidence of the very small amount of detritus that falls over the bottom.

Causes limiting Distribution.—The two prominent physical causes limiting distribution are the amount of (1) heat, and (2) light.

1. *Temperature.*—The temperature of the water varies (1) with the zones, from 90° F. in the tropics, to 32° F., and even 28° F., in the polar seas; (2) with the distribution of marine currents, the warm currents from the equatorial regions, and the cold from high latitudes; (3) with the depth, the temperature diminishing downward to 35° F. as a general thing, but in some places to 28° in the polar regions and polar currents. There is even in the tropics a temperature of 45°, and often of 40°, within 300 fathoms of the surface, and almost everywhere of 40° or less, below 1000 fathoms; so that, from 1000 fathoms to the greatest depths, the variation is only from 40° to 32° F., or in extreme cases to 28° F.

The influence of marine currents on the temperature is great. The Gulf Stream, a deep Atlantic current, carries heat from the tropical to the polar seas. The portion of the broad current which passes through the Florida Strait is as deep as the strait (400 fathoms), and 83° to 44° F. in temperature, and has a maximum velocity of 5 miles an hour. It washes the deep-water border of the Atlantic basin at depths between 60 and 300 fathoms off South Carolina, and between 60 and 150 fathoms (Verrill) southeast of New England; crosses the ocean northeastward to the British seas, and has a temperature of 45° off the Faroe Islands at a depth of 600 to 800 fathoms; and thence continues on poleward. From the polar regions the waters, chilled down to 39° to 28° F., flow back, as the Labrador Current along the east coast of America, and also southward beneath the warmer current over the ocean's depths to the equator and beyond. Comparatively little goes out through Bering Strait, because the depth is only 150 feet.

In the Pacific, there is a warm or tropical current on the west side, answering to the Gulf Stream of the Atlantic.

Again, on the east side of the South Pacific, a reverse flow exists: a cold-water current from the southwest strikes the submarine slopes of southern South America, and carries cold to the equator, and thus narrows the region of tropical waters.

The range of temperature favorable to any marine species is small — generally not over 20° F., and often less than 15° F. Within the favorable temperature the species thrives; approaching the limit, the size usually diminishes; and beyond it, growth and egg-development cease. A current too cold for species within its reach is destructive, even more so than one of too much warmth.

2. *Light.* — Light is the chief limiting cause as to depth (Fuchs). If it were temperature, multitudes of species might grow hundreds of feet below their present level. Light has been found by experiment to penetrate downward in the ocean a little more than 200 fathoms; but the light becomes very feeble long before this limit is reached. The species of shallow waters differ to a large extent from the deep-sea species; they are (as stated by Fuchs) the species of the light, the latter the species of the darkness. The two groups of species, the ocean-border species (or those of the light) and the deep-sea species (or those of the darkness) are mingled somewhat between depths of 30 and 90 fathoms, and some shore species extend down to a much greater depth.

The eyes of animals of the dark sea depths are often rudimentary, or else unusually large. The blindness is evidence of darkness; and the large eyes, of adaptation to the very feeble light of the regions. But this feeble light may be, as Dr. Carpenter, Wyville Thomson, and others have supposed, that of phosphorescence, since many Crustaceans, Alcyonarians, Starfishes, and other animals are brightly phosphorescent.[1]

[1] The following are enumerated as the most characteristic types of the dark sea depths: — of Corals, Oculinidæ, Cryptohelia, and various solitary species; the Vitreous Sponges; Crinoids (Pentacrinus, Rhizocrinus, Hyo-

The Border Region. — Over the ocean's border region not only is the diversity of temperature between the equator and the poles felt in full force, but also that produced by the warm and cold currents. Off eastern North America down to Cape Hatteras, the cold Labrador current cools the waters over the border region between the Gulf Stream and the shore line; while south of this cape the Gulf Stream has possession.

The other causes limiting distribution in the border regions of the ocean are: (1) the condition of the water, whether pure, or impure from sediments and fresh waters received from the land; (2) the character of the bottom, whether of mud, sand, or rock, and whether firm, or easily stirred by waves or currents.

Reef-forming Corals grow only in the sea-border regions of tropical seas, and at shallow depths. They extend from the equator to about latitude 28°, on the average, where the sea temperature of the coldest month is not below 68° F. Owing to the warm Gulf Stream, they occur in the Atlantic in 32° north latitude, Bermuda being of coral formation; and, owing to the cold waters off western South America, they are excluded from that coast south of Guayaquil. In depth the limit is 20 to 25 fathoms. A vast variety of tropical animals live and find shelter among coral reefs.

Seaweeds, like most other plants, are species of the light; they grow mostly within 10 fathoms of the surface, and rarely beyond 30.

The Sea Depths. — In this region, the range of temperature is for the most part small — 55° to 30°. Only two well-marked divisions exist: that of the cold depths, the temperature below 45° F.; and that within the range of the tropical currents (as the Gulf Stream in the North Atlantic), the temperature mostly 45° to 55° F.

crinus, Bathycrinus); of Echinoids, Echinothuriæ, Pourtalesiæ, Ananchytidæ; of Asterioids, Brisinga; Holothurians of suborder Elasmopodia; and Fishes, ribbonlike in form, of the families Lepidopidæ, Trachypteridæ, Macruridæ, and Ophidiidæ.

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The border of the Atlantic basin where swept by the Gulf Stream (page 93), both on its west side and in the British seas, is crowded with life — species of Crustaceans, Echinoderms, Polyps, Mollusks, Worms, Fishes; and some kinds are larger than any of the same groups found in shallower waters. Wyville Thomson mentions his bringing up 20,000 specimens of one species of Sea Urchin at one haul; and Verrill and Agassiz state parallel facts from the American seas.

The life from the cold and warmer regions differs to a great extent in species; but the more comprehensive groups represented in the two are largely the same. The colder depths are much less profuse in life, fail of some prominent groups, and contain many species of very peculiar character.

The cold and warm currents are in places in abrupt contact. The pushing of the former, along the eastern submerged border of North America, over the narrow warmer area, in consequence of a severe storm, was probably the cause of the destruction of Fishes, Crustaceans, etc., that took place during the winter of 1881–82 (A. E. Verrill).

PART III. — DYNAMICAL GEOLOGY.

Dynamical Geology treats of the causes or origin of events in geological history — that is, of the origin of rocks, of disturbances of the earth's strata and the accompanying effects, of valleys, of mountains, of continents, and of all changes in the earth's features, climates, and living species. The agencies of most importance, next to the universal powers of Gravitation and Cohesive and Chemical Attraction, are Life, the Atmosphere, Water, and Heat.

The following are the subdivisions of the subject here adopted: —

1, Life; 2, The Chemical Action of the Atmosphere and Waters; 3, Mechanical Effects of the Atmosphere; 4, Mechanical Effects of Water; 5. Action of Heat; 6, Movements in the Earth's Crust, including the folding and uplifting of strata, and the origin of mountains and of the earth's general features.

I. LIFE.

Life has done much geological work, by contributing material for the making of rocks. Nearly all the limestones of the globe, all the coal, and some siliceous beds, besides portions of rocks of other kinds, have been formed out of the remains of living organisms. Both animals and plants have been sources of the material. The skeletons, or stony secretions, of animals, after fulfilling the purposes of life, have been turned over to the mineral kingdom, to be made into minerals and rocks. Similarly, from vegetable structures have come beds of stone, as well as beds of coal. Moreover, fossils, or relics revealing the form or structure of once living creatures, are common in the rocks. This is the formative work of life.

Life has done geological work also through its protective and its destructive effects.

1. Formative Work.

Aquatic Species the Principal Rock-makers. — The kinds of life which have contributed most material to the earth's rock formations, and which are most common as fossils, are the aquatic, and particularly the marine. This is so for several reasons.

(1) The accumulation of material for beds of rock has been done mostly by the sea.

(2) The species which have the most stony matter in their structures, viz., Corals, Crinoids, Mollusks, and Molluscoids, are, with inconsiderable exceptions, aquatic, and the great majority are marine.

(3) The animal remains which are covered by the water itself, or by the sediments deposited therein, are protected from the chemical action of the atmosphere, and from various other destructive agencies. Coal has been made only where the plants grew in or near marshes or shallow lakes, or were drifted into bays or lakes ; for the leaves that fall in the dry woods undergo complete decomposition, and pass away in gaseous combinations. The bones of animals dropped over the land disappear by becoming the food of other animals, as well as by decay. But those of Mammals, Birds, and Reptiles living about the shores of lakes, have often become buried in lacustrine deposits of sand or mud, and thus have been preserved. Mastodons have been mired in marshes, and their skeletons preserved whole, while the thousands that died over the

dry land left no relics. The wings and other parts of Insects have been kept perfect, and in great numbers, in the muds of some ancient ponds.

Shells, bones, corals, etc., after fossilization, have rarely their original composition. They have in almost all cases lost at least the animal matter they contained, and thus become friable. But frequently they are petrified; that is, the original material is replaced by quartz, calcite, or (less commonly) pyrite, oxide of iron, an ore of copper, or a silicate of some kind. Wood is often thus changed to quartz, or to calcite, making what is called petrified wood.

Besides water, the resins that have exuded from coniferous and other trees have been good at catching and preserving Insects, Spiders, and Myriopods — the smaller flying and crawling things of a forest. The resin has usually undergone a change to amber or some similar substance.

The preceding review of the kingdoms of life brings out prominently the fact that only animals of rather low grade consist largely of stony secretions. Rhizopods, Corals, Crinoids, Brachiopods, and Mollusks, among animals, and Nullipores, Corallines, and some other Algæ, among plants, are the chief workers at rock-making, for the reason that they may consist one half or more of stone, and yet carry on the processes of life.

CALCAREOUS FORMATIONS; LIMESTONES.

The method of forming limestones is, in general, the same, whether the source of the calcium carbonate be shells of Mollusks or Brachiopods, or tubes of Worms, or Crinoids, or Anthozoan corals, or Hydrozoan corals, or Bryozoan corals, or vegetable corals, as Nullipores and Corallines. If shells are in great profusion, there will pretty certainly be also some of the various species of corals, if the temperature of the seas favor; and over coral reefs, where Anthozoan corals are the prominent growth, shells of many species also abound, with more or less of Millepores and Nullipores. Whatever the species, the process is the same. An account of the formation of limestone from coral reefs will therefore serve as a general illustration of the subject.

Coral Reefs and Islands.

In tropical regions, corals grow in vast plantations about most oceanic islands and along the shores of continents, with a profusion of other marine life. In the shallow waters the patches or groves of coral are usually distributed among larger areas of coral sand, like small groves of trees or shrubbery in some sandy plains.

The coral plantations are swept by the waves, and with great force when the seas are driven by storms. The corals are thus frequently broken, and the fragments washed about until they are either worn to sand by the friction of piece upon piece, or become buried in the holes among the growing corals, or are washed up on the beach. Corals are not injured by mere breaking, any more than is vegetation by the clipping of a branch; and those that are not torn up from the very base and reduced to fragments continue to grow.

The fragments and sand made by the waves, and by the same means strewn over the bottom, along with the shells of Mollusks and other calcareous relics, are spread out in a bed in the shallow water like any sedimentary material. The bed consolidates as accumulation goes on, and thus becomes a bed of limestone.

As the corals continue growing over this bed, fragments and sand are constantly forming, and the bed of limestone thus increases in thickness until it reaches the level of low tide. Beyond this it rises but little, because corals cannot grow where they are liable to be left for hours wholly out of water; and the waves have too great force at this level to allow of their holding their places, if they were able to stand the hot and drying sun. A bed of limestone is thus produced, which is the coral reef.

The coral reef at or just above low-tide level is often covered with a thick growth of Nullipores. Millepores and Corallines sometimes grow in large patches among the other corals of the plantation. Occasionally, as has been observed at Bermuda and Florida, the tubes of Worms (*Serpulæ*) furnish important contributions of material.

The limestone beds made from corals and shells are not a result of growth alone, as in the case of the deposits formed from microscopic organisms, but of growth in connection with the breaking and wearing action of the ocean's waves and currents. Corals and shells, unaided, could make only an open mass full of large holes, and not a compact rock. There must be sand or fine fragments at hand, such as the waters can and do constantly make in such regions, in order to fill up the spaces or interstices between the corals or shells. If there is clayey or ordinary siliceous sand at hand, this will suffice, but it will not make a pure limestone; in order to have the rock a pure limestone, the shells and corals must be the source of the sand or fine fragments, for these alone yield the needed calcareous material or cement. The limestone made in this way by the help of the waves may be, and often is, of impalpable fineness of grain, having been formed, in such a case, of the finest coral sand or mud. In other cases, it contains some imbedded fragments in the solid bed; in others, it is a coral conglomerate; and, over still other large sheltered areas, it is a mass of standing corals with the interstices filled in solid with the sand and fragments.

Along the shores, above low tide, the sands are agglutinated into a beach sand-rock, and the beds have the slope of the beach, or 5° to 15°. The waters contain calcium bicarbonate in solution; and, as the sands, wet at high tide, dry again when the tide is out, the calcareous cement is deposited between the grains as calcium carbonate, and so consolidation goes forward. The cement coats each grain with calcium carbonate, and in this way the rock sometimes takes the character of an oölite.

The calcareous sands left dry on the upper part of the beach may be blown inland by the winds, and piled in dunes, consolidating into a wind-drift rock, or æolian rock. This has occurred on a large scale at Bermuda and the Bahamas (page 121).

FIG. 153.

View of a high island, bordered by coral reefs.

The coral formations of the Pacific are sometimes broad reefs around hilly or mountainous islands, as shown in Fig. 153. To the left, in the figure, there is an inner reef and an outer reef, separated by a channel of water, the inner (*f*) called a fringing reef, and the outer (*b*) a barrier reef. They are united in one beneath the water. At intervals there are usually openings through the barrier

FIG. 154.

Coral island, or atoll.

reef, as at *h*, *h*, which are entrances to harbors. The channels are sometimes deep enough for ships to pass from harbor to harbor. Some islands are surrounded only by a fringing reef, close to the shore; others only by a barrier reef, separated from the shore by a channel several miles in width.

Many coral reefs stand alone in the ocean, far from any other lands. A view of one of these coral islands, or atolls, is shown in Fig. 154, and a map in Fig. 155. An atoll consists of a reef encircling a salt-water lake, called the lagoon. On the windward side the reef first rises above the surface, and becomes covered with vegetation. Very often, as in Fig. 155, the leeward part of the belt is dry only at low tide, or wooded only in spots, so as to be a string of green islets. There are sometimes deep openings through the reef on the leeward side, as at (*e*) in Fig. 155, so that ships can enter the lagoon and find good anchorage. Fig. 155 is a map of one of the atolls of the Gilbert (or Kingsmill) Islands in the Pacific.

FIG. 155.

Apia, of the Gilbert group, Pacific.

The Paumotu Archipelago, east-northeast of the Society Islands, contains between 70 and 80 atolls; the Carolines, with the Radack, Ralick, and Gilbert groups, on the east and southeast, as many more; and others are scattered over the intervening ocean. Most of the high islands between the parallels of 28° north and south of the equator (where the seas are sufficiently warm, page 95) have a fringe or barrier of coral reefs.

The extent of some of the modern reefs matches nearly that of the largest Paleozoic reefs. On the north of the Fiji Islands the reef grounds are 5 to 15 miles in width. The barrier reef of New Caledonia extends 150 miles north of the island and 50 miles south. Along northeastern Australia the reefs extend, although with many interruptions, for 1000 miles.

Since the reef-forming corals grow only where the depth is not more than about 150 feet, the thickness of the reef cannot much exceed that amount, if the sea bottom remains at a constant level. But in the vicinity of many barrier reefs, and of atolls in general, soundings show a depth of hundreds or thousands of feet, apparently indicating for the reefs a thickness vastly exceeding the depth which is the limit of coral growth. Darwin exfrom the excrements of Birds in dry regions where the Birds long had undisturbed possession; as on some small coral islands in the central Pacific, islands off the Peruvian coast, the coast of equatorial Africa, and in the Caribbean Sea. Over the coast regions of South Carolina, Georgia, and Florida, there are large phosphatic deposits of great commercial value.

Coprolites, or isolated excrements of Reptiles and Fishes, and sometimes of other animals, occur in many rocks.

The shells of certain Brachiopods — *Lingula* and some related genera — are largely phosphatic. These shells and the shells of Crustaceans, when fossilized, are usually black, because of the large amount of animal matter they contain, this portion becoming carbonized.

Vegetable tissues also afford phosphates, the ashes of ordinary meadow grass affording 8 parts of phosphoric acid in 100; of rye straw, 4 parts; of clover, 18 parts; of seaweeds, 1 to 5 parts.

SILICEOUS FORMATIONS.

Siliceous beds of organic origin are made chiefly from the accumulation of the shells of Diatoms, and, in the tropical ocean more especially, from those of Radiolarians. Diatom deposits are common in marshes beneath the peat of the marsh. They were made while the marsh was in the state of a pond. The deposit looks like chalk, but shows under the microscope that it consists chiefly of the shells of Diatoms. Moreover, the material does not effervesce with acids like chalk or limestone. It is used as a polishing powder, also in making giant powder or dynamite preparations, also for making "soluble silica."

Some Algæ living in the geysers of the Yellowstone Park secrete silica, and thus make siliceous growths and accumulations, as first observed by W. H. Weed.

Such deposits of organic silica often become solidified by infiltrating waters, and so converted into opal or chalcedony.

depths; and among them those of Pteropods, pelagic species, are common in some places.

Fresh-water Shell Limestone.

Fresh-water shells, especially those of the genera *Sphærium*, *Limnæus*, *Physa*, *Planorbis*, and *Paludina*, make white, often chalky, beds on the bottoms of small ponds; which, as the pond shallows, become overlain by a growth of peat. In such accumulations, the shells are sometimes but little broken, and they then make shell limestone. The large shells of the *Unio* group, the Fresh-water Mussels of rivers, occasionally make beds, but seldom of much extent.

PHOSPHATIC FORMATIONS.

Vertebrate animals have contributed very little material to the rocks, compared with inferior tribes of animals. But they have been an important source of calcium phosphate, and the deposits are often worked, because the material is valuable as a fertilizer. Bones, scales, and various tissues of both Vertebrates and Invertebrates contain phosphatic material. The mineral apatite, common in many crystalline limestones, is a calcium phosphate, and is sometimes of organic origin. Guano, which owes its value largely to its phosphates, has been made chiefly

depth at which reef corals can grow, — and that only the upper 150 feet consists of coral rock. The great depth of the lagoons in many of the larger atolls is not very satisfactorily explained on Murray's theory; and many facts in regard to coral formations — as, for instance, the succession of small atolls, large atolls, barrier reefs, and fringing reefs, in passing outward from the central area of the Pacific, which is destitute of islands — are better explained on the theory of subsidence. A few borings in a coral island to a depth of 500 or 1000 feet, with a drill large enough to give a core six inches in diameter for examination, would settle the question as to whether the rock below is of coral-reef origin or not. The notion formerly entertained, that atolls have been formed upon the rims of submarine craters, involves so many improbabilities that it has been universally abandoned.

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Organic silica has been largely distributed through limestones while they were in the process of formation, because Diatoms, Sponges, and Radiolarians were living in the same waters that supplied the shells, corals, and other materials of the limestones. Through the tendency of particles of the same kind of matter diffused through a rock to collect and concrete together, being carried by percolating waters in a state of solution or suspension, the limestones are now filled with siliceous concretions. The flint which constitutes concretions of irregular form in some beds of the English chalk, and the chert, or hornstone, of many limestones, have been thus derived. Moreover, in the petrifaction of the fossils of a limestone or other rock by silica, the silica has often come from this organic source.

CARBONACEOUS FORMATIONS; PEAT, COAL, ETC.

The most abundant contributions from the vegetable kingdom to rocks are those constituting beds of mineral coal, coal being made from woody tissues as the result of a more advanced stage of the same process by which peat is formed (as explained below). Mineral oil has in part the same source, but is chiefly of animal origin. Graphite, which is pure carbon, is often also of vegetable origin, coal sometimes occurring changed to graphite when it has been subjected to high heat under pressure. Carbonaceous matter, of vegetable or animal origin, gives the black color to black limestones and shales, as it does to soils. This is proved by the fact that, when such rocks are burnt, they become white, owing to the combustion of the carbonaceous part.

Peat Formations.

Peat is an accumulation of half-decomposed vegetable matter formed in wet or swampy places. In temperate climates it is due mainly to the growth of mosses of the genus *Sphagnum*. These mosses form a loose, spongy turf; and, as they have the property of dying at the extremities of the roots while increasing above, they may gradually form a bed of great thickness. The roots and leaves of other plants, or their branches and stumps, and any other vegetation present, may contribute to the accumulating bed. The small Crustaceans, Worms, and various other organisms living in the waters, including often fresh-water Sponges, add to the material; the siliceous spicules of the Sponges may generally be found in the ashes of the peat. The carcasses and excrements of large animals at times become included. Dust may also be blown over the marsh by the winds.

In wet parts of Alpine regions there are various flowering plants which grow in the form of a close turf, and give rise to beds of peat, like the moss. In Tierra del Fuego, although not south of the parallel of 56°, there are large marshes of such Alpine plants, the cool summers which prevail in that latitude in the southern hemisphere giving the vegetation an Alpine character even at low altitudes.

The dead and wet vegetable mass slowly undergoes a change, becoming an imperfect coal, of a brownish black color, loose in texture, and often friable, although commonly penetrated with rootlets. In the change the woody fiber loses a part of its oxygen and hydrogen; but, unlike the typical varieties of coal, it still contains usually 25 to 33 per cent of oxygen. Occasionally it is nearly a true coal.

Peat beds cover large surfaces of some countries, and occasionally have a thickness of forty feet. One tenth of Ireland is covered by them; and one of the "mosses" of the Shannon is stated to be fifty miles long and two or three miles broad. A marsh near the mouth of the Loire is described by Blavier as more than fifty leagues in circumference. Over many parts of New England and other portions of North America there are extensive beds. The amount of peat in Massachusetts alone has been estimated to exceed 120,000,000 cords. Many of the marshes were originally ponds or shallow lakes, and gradually became swamps as the water, from some cause, diminished in depth.

Peat is often underlain by a bed of whitish shell marl, consisting of fresh-water shells — mostly species of *Limnæus*, *Physa*, and *Planorbis* — which were living in the lake. Beds of white chalky material consisting of the siliceous shells of Diatoms, referred to on page 106, are often found beneath peat.

Peat is used for fuel, and also as a fertilizer. ***Muck*** is another name of peat, and is used especially when the material is employed as a manure; but it includes all impure varieties not fit for burning, being applied to any black swamp earth consisting largely of decomposed vegetable matter.

Peat beds sometimes contain standing trees, and entire skeletons of animals that had sunk in the swamp. The peat waters have an antiseptic power, and flesh is sometimes changed by the burial into adipocere.

2. Protective and Destructive Effects.

Slopes are protected from erosion by a covering of turf; sand hills, from the winds, by tufts of grass and other vegetation; shores, from the surf in many places, by a growth of long seaweeds; and the outer margins of coral reefs, by a growth of Nullipores over the exposed surface.

Further, forests keep a vast amount of moisture in the wet ground beneath them, which is gradually supplied to the streams as from a reservoir, making them serviceable for mills and other purposes through the year; whereas, if the forests are cut away, the rains fill suddenly the river channels, producing disastrous floods, and the long droughts which intervene are seasons of dwindled and useless waters. And, besides, the floods carry away the soil from the steep hillsides, and may reduce a productive region to one of rocky ledges. These evils are already a reality in portions of North America, and are on the increase.

The common Earthworm, as Darwin has shown (1881), moves a great amount of earth or soil in the pellets it discharges at the surface. He found that the weight per acre in a year in four cases was 7.56, 14.58, 16.1, and 18.12 tons. Lobworms, on seashores, are even greater workers, according to C. Davison, who reports that the amount of sand carried up each year on the shores of Holy Island, Northumberland, was equivalent to 1911 tons per acre (1891). Marmots (*Spermatophilus Eversmani*), in the Caspian steppes, bring great quantities of earth to the surface. In a few years after their introduction they had brought up 75,000 cubic meters of earth to the square mile (Muschketoff, 1887). The loosening of the soil by such means allows it to be more easily washed away by rains.

Rocks, where jointed or fissured or laminated, are often torn asunder or upturned by the growth of a seed in a crevice, and the subsequent enlargement of the root and stem — trunks sometimes growing to a diameter of several feet, and gradually opening the crevice, and thus displacing great masses. The same agency opens crevices to moisture, and so promotes decomposition; and it prepares for the action of freezing in winter (page 157).

Boring animals cause destruction in various ways. The Mole, Mouse, and some other animals tunnel embankments, and open channels which the exit of the confined waters rapidly enlarges; and sometimes a vast amount of erosion is occasioned by the waters thus discharged. The levees of the Mississippi are thus tunneled by Crawfish, occasioning great floods and devastations. Boring shells, as the *Saxicava*, weaken the parts of rocks exposed to the surf.

The decay of vegetable and animal matters in the soil produces organic acids as well as carbonic acid, which corrode rocks and promote their decomposition.

II. CHEMICAL ACTION OF THE AIR AND WATERS.

Geological work of a destructive kind is carried forward in a quiet way through the chemical action of the constituents of the earth's atmosphere and waters, preparing thus for the rougher mechanical work of these agents; and the same processes have their formative effects.

1. Destructive Effects.

Oxygen is a constituent both of air and water, it being mixed (in the proportion of 23.1 per cent by weight) with nitrogen to form air, and combined (in the proportion of 88.89 per cent) with hydrogen to form water (H_2O). Many substances in minerals or rocks have an intense affinity for oxygen.

Iron rusts because of its tendency to combine with oxygen; and iron in the protoxide state, or ferrous oxide (FeO), will take more oxygen, and so pass to the sesquioxide state, or ferric oxide (Fe_2O_3). Consequently, a mineral containing iron in the former state, as pyroxene, hornblende, or black mica, often goes to destruction through this affinity; and hence rocks containing these minerals, like trap, usually suffer easy decomposition; for disturbing one constituent is, like taking a stone from an arch, destruction to the whole. The other ingredients of the iron-bearing mineral are set free to make earth, and commonly the associated minerals participate in the decay and add to the earth. The ferric oxide may make a red earth (red ocher), which is one form of the species hematite. But it generally combines with water, and becomes a brownish yellow earth, which is yellow ocher, or the mineral called limonite. The hematite or limonite may be pure, but it is usually mixed with the other materials of the rock, or makes ocherous stains over the surfaces of fissures or joints.

In this process of oxidation, moisture as well as air must be present; the oxygen taken up is usually derived from the moisture.

Again, iron when combined with sulphur, constituting a sulphide of iron, like pyrite or marcasite (FeS_2), or pyrrhotite ($Fe_{11}S_{12}$), oxidizes readily (unless in the firmest crystals), and passes to the same state of yellow ocher, or limonite. The sulphur also oxidizes, and becomes sulphuric acid, which is a destructive agent, owing to its tendency to take into combination many of the ingredients of minerals, as lime, magnesia, soda, potash, alumina, and iron oxides, making sulphates; and it hence aids much in the work of destruction. This acid may combine with the iron, and so make green vitriol; but, as its affinity for the other substances above enumerated is stronger than for iron, the iron is usually left in the ocherous state.

Now iron sulphide, in the form of pyrite or marcasite, is disseminated more or less abundantly through nearly all the rocks of the globe. Hence, rocks in all lands are undergoing destruction through this agency. Many a fair-looking stone is worthless for building on account of it. It is the most universal of rock destroyers. When the minute grains of pyrite in a granite or sandstone oxidize, the other mineral particles of the rock are set loose, and become discolored with the ocher that is made; and the sulphuric acid, formed at the same time, eats into some of them to cause their decomposition. Thus the granite either (1) disintegrates into a loose granitic sand, or (2) becomes decomposed to earth or clay. Blocks of trap have a thin decomposed crust, which is incessantly receiving additions inside while losing outside.

The decomposition of iron sulphide in shales or clays often forms alum, and makes alum clays, because of the combination of the sulphuric acid that is formed with the alumina of the rock, and usually with some other element in the protoxide state, as potash, soda, magnesia, etc.

When iron carbonate (siderite) is left exposed to the air and moisture, the iron oxidizes, and the surface color changes from grayish white to brown, yellowish, or black, owing to the formation of limonite. An exposure to the weather for a year is sufficient to cause a superficial change; and by continued exposure the whole mass becomes limonite. Crystalline limestone, when pure calcite ($CaCO_3$) or pure dolomite ($CaMgC_2O_6$), is a durable rock. Columns, statues, and pinnacles, as in the marvelous Milan cathedral, will stand exposure to the weather almost indefinitely. But, if the limestone contains one per cent of iron combined with the calcium, the iron will soon show itself over the exposed surface by giving it an iron-rust color, and the destruction of structures made of it is sure to follow. If manganese is present instead of the iron, the destruction of the rock is equally certain, but the stains produced are black. To prevent evil to marble buildings, blocks of such limestone are sometimes smeared with tar over all their surfaces, except those exposed to view.

Carbon Dioxide and Organic Acids. — Carbon dioxide is present in the atmosphere, about 3 parts in 10,000 consisting of this gas. It is present in all rain water, the rain water deriving it from the atmosphere. It is present in the soil, being produced wherever the material of plants and animals is undergoing decomposition; and thence it is given to the waters percolating through soils. By all the methods mentioned, and also through animal respiration, the sea derives carbonic acid. Moreover, in the earlier ages of the globe, the amount of carbonic acid in the atmosphere and waters was far greater than at present. Organic acids result from the decomposition of vegetable and animal materials in the soil; and, like carbonic acid, are carried by the waters of the soil downward through the porous rocks.

Carbonic acid tends strongly to form combinations with magnesia, lime, potash, soda, and with iron in the protoxide state. Hence a feldspar, since it contains potash, soda, or lime, is liable to have its alkali carried off by percolating waters; and, with such a loss, the mineral changes to a hydrous clayey mineral called kaolin—the material used in making porcelain. Common feldspar yields on analysis 17 per cent of potash, 18.5 of alumina, and 64.5 of silica; and kaolin yields no potash, 14 per cent of water, 40 of alumina, and 46 of silica. Granite and other rocks are often eaten into by this process, so as to be fragile to the depth of a foot or more, and sometimes to a depth of 50 or 100 feet. Like results are produced by organic acids in percolating waters.

The depth of decomposition is determined by the depth to which moisture is absorbed; so that the architectural value of a stone is inversely as its absorbent quality. All cracks or joints by which water enters may have a discolored border (Fig. 157); and the process goes on by this means, in some granite, trap, and other rocks, until the mass becomes reduced to what looks like a pile of large spheroidal concretions (Fig. 158); and ends finally in making earth, or loose sand, of the whole.

Fig. 157.

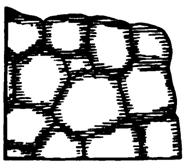
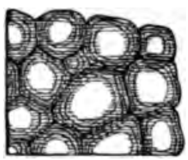


Fig. 158.



Decomposition of rocks along cracks.

The decomposition of iron-bearing minerals is promoted by the action of carbonic acid, or of organic acids contained in the soil waters. These acids extract the iron protoxide and make with it a soluble salt of iron, and thus, by the aid of streamlets, may carry the iron away. The salt of iron generally becomes oxidized in the low places or marshes to which it may be carried, and forms there a yellow or brown or brownish black deposit of limonite or a related ore.

In regions of dry climate, like a large part of the Rocky Mountain region, the waters percolating through porous rocks, as sandstones, bring to the surface of the rock the soluble iron compounds produced within it by decomposition; and, by the deposit of the iron in the form of ferric oxide, give to the lofty walls and bluffs of cañons and plateaus brilliant colors of buff, yellow, orange, vermilion, and other shades; and often the tints are in vertical bands or stripes, owing to the descent of the solution along the vertical surfaces. These colors prevail through Colorado, Utah, Montana, Wyoming, and other states north and south. They gave the name of Yellowstone to the large lake and river so called, and to the Yellowstone Park in northwestern Wyoming. Were rains abundant, the iron-made tints would be washed out by the descending waters, and only the commonplace grays and dull reds remain.

The organic material of the soils, owing to its using oxygen when decomposing, will take it from any Fe_2O_3 present, and may thus change it to FeO, and this FeO may then combine with the organic acid or carbonic acid at hand. Many red beds of rocks have lost the red color in spots or seams or along cracks, by this method of deoxidation.

When calcareous grains or fossils are distributed through beds of porous siliceous sandstone, percolating waters will carry off the grains and fossils. But, if the rocks are not porous, such fossils remain for indefinite time. Moisture usually penetrates a compact rock to a very small distance —generally less than an eighth of an inch, — and only to this depth does change go forward. The frequent preservation of calcareous fossils, and the unaltered state of the minerals of much granite and trap, show that infiltration and change have ordinarily very narrow limits.

Waters containing carbonic acid readily erode limestone. The limestone is converted into calcium bicarbonate, which is soluble. On exposure to the air, the bicarbonate loses its excess of carbonic acid, and the limestone taken up is again deposited. Thus limestone strata are eroded, and caverns made; and, by the depositions, the caverns are hung with stalactites and floored with stalagmite. (See pages 40, 144.)

III. MECHANICAL EFFECTS OF THE ATMOSPHERE.

The Atmosphere does mechanical work in denudation, transportation, and deposition of rock material. It also accomplishes, indirectly, important geological work by the transportation of moisture. Its work is called Æolian work, from the classical name for the god of the winds.

1. Denudation, Transportation, Deposition.

The force of the wind in its movements against objects varies as the square of the velocity. Supposing the air to be of mean density at 60° F. near the ocean's level, the pressure it exerts on a square foot at a velocity of 5 miles an hour is equal to about 2 ounces; at a velocity of 10 miles, or that of a light breeze, 8 ounces; of 20 miles, a good steady breeze, 2 pounds; of 40 miles, a strong gale, 8 pounds; of 60 miles, 18 pounds; of 100 miles, 50 pounds.

But the density diminishes with increasing temperature, and with increase of height above the sea level. The diminution is one half at a height of 3½ miles.

Denudation. — The work of denudation is carried on by the winds, by (1) the direct impact of the air, and (2) abrasion by means of transported sand and pebbles.

Great effects from impact require that broad surfaces of unstable structures (as the side of a house) should be exposed to the moving air, and the effect is greater where the surfaces struck are concave. Broad tracks of prostrate trees across a forest are examples of such work. Moreover, loose stones may be dislodged from natural walls by the same means, besides the sand and fragments made by slow decomposition or weathering over their surfaces.

Abrasion by transported material is another important travertine of Tivoli, near Rome, and the deposits of Gardiners River, Yellowstone Park. Such deposits are formed in many rivers that flow through limestone countries, and in lakes into which such rivers flow.

4. In dry countries, lakes without outlets often occur, the inflow of water being balanced by evaporation, so that the water in the lake is unable to rise to a level at which it can find an outlet. In such lakes the soluble materials present in river waters may accumulate to supersaturation, and be deposited. In regions where marine sediments are the prevailing rocks, the soluble ingredients taken up by the rivers will be largely the same that exist in sea water, as common salt (sodium chloride) and gypsum (calcium sulphate). In regions of volcanic rocks, alkaline carbonates, derived from the decomposition of the feldspars and allied minerals, will be more abundant than chlorides. Salt lakes may also be formed by the isolation of portions of the sea by elevation of portions of the earth's crust. In the progressive concentration of salt lakes, gypsum is first deposited, being comparatively little soluble, and afterwards the salt. Deposits of salt and gypsum may be formed also in salt marshes and lagoons along seashores.

Consolidation of Rocks. — Carbonated waters, besides serving in the consolidation of limestones (page 101), often also consolidate sand beds, gravel beds, and clay beds, when grains of limestone are even sparingly present, through alternate wetting and drying. Very commonly the solidification in beds of clay and sand takes place around centers (some grain, or it may be fossil, serving as the nucleus), making concretions (page 46) in the bed. The making of concretions may end in complete consolidation. Again, consolidation takes place to some extent through the deposition of limonite over the surfaces of pebbles in gravel. But the most common method of solidifying such fragmental deposits is through siliceous waters (page 194).

Transportation and Deposition. — The streets of most cities, as well as the roads of the country, often afford examples of the drifting power of the winds; and the burial of ancient Rome and of Egyptian monuments is among its effects. The moving sands of seashores and deserts afford the best opportunity for the study of its methods of work.

The transporting power of air is small compared with that of water, because of its lightness and want of cohesion. Ordinary stony material, such as common sand, is 2100 times heavier than dry air, while only 2.5 to 2.7 times heavier than water. A strong breeze is therefore required to raise the dust of a road for transportation, and a still stronger breeze to raise quartz sand; while large pebbles are seldom lifted from the ground.

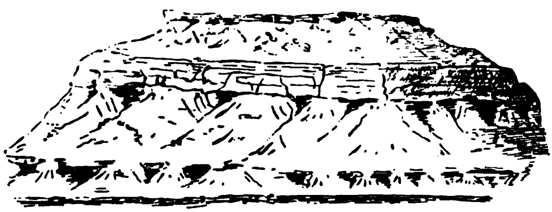
The winds, moreover, are extremely irregular in their movements and action. The trades, over the ocean, have a degree of uniformity. But they have a velocity generally of only 10 to 20 miles an hour. The winds that do the chief part of æolian geological work are those of storms, whose velocity per hour is from 40 to more than 100 miles. Such winds are very unsteady in action, blowing in blasts or gusts, in which there is a sudden increase to a maximum and a slower decline to a minimum. There is no constancy in force even for an hour, and no uniformity over large areas.

In these and other ways, air manifests its unsteady character as a geological agent, and contrasts strongly with water. As a consequence, the transporting power of the strong winds undergoes rapid variations. The wind that carries and drops pebbles, a few minutes later carries only sand for deposition, and finer sand follows coarser.

As a consequence, æolian deposits are generally straticulate, finer and coarser laminæ succeeding each other in indefinite alternations. But there is not the evenness of layer characterizing aqueous deposits, even when made over level surfaces. To make beds without straticulation means of denudation. The sands carried by the winds over the surfaces of rocks sometimes wear them smooth, or cover them with scratches and furrows, as early observed by W. P. Blake on granite rocks at the Pass of San Bernardino, in California. The different minerals in the granite were found to stand out more or less prominently over the rock, according to hardness.

In the more arid regions of the Rocky Mountains, and in deserts elsewhere, mountain ledges have been deeply worn, and bold bluffs shaped, so as to present the features usually derived from denudation by water. The following sketch (Fig. 160) gives a good idea of the power of the winds at rock sculpture, and affords also a suggestion as

FIG. 160.



Æolian denudation in the Egyptian desert.

to the great diversity of scenery that æolian work may produce. It represents a scene in the Egyptian desert. The softer layers or strata are worn most deeply, and the harder left to cap the hills and form cornices and lines of molding.

Glass in the windows of houses on Cape Cod sometimes has holes worn through it by the same means. The hint from nature has led to the use of sand driven by a blast for cutting and engraving glass, and even for cutting and carving granite and other hard rocks.

The transported sands also rub against and wear one another. This mutual attrition makes the sand grains smaller, and produces also the finest of dust, the lightest of the wind-drift materials.

shells and corals, in Bermuda, have a height of 100 to 250 feet. Similar drift hills occur at the Bahamas. Such hills of calcareous sands consolidate through alternations of wet and dry, and thus exhibit well in sections the irregular dip of the layers.

The drifting of sand is a means of recovering lands from the sea. The appearance of a bank at the water's surface off an estuary at the mouth of a stream is followed by the formation of a beach, and then the raising of hills of sand by the winds, which enlarge till they sometimes close up the estuary, exclude the tides, and thus aid in the recovery of the land by the deposition of river detritus. Lyell observes that at Yarmouth, England, thousands of acres of cultivated land have thus been gained from a former estuary. In all such results the action of the waves in first forming the beach is a very important part.

Drift sands sometimes overwhelm and destroy forests and cultivated lands. East of Lake Michigan the sand hills extend to a height of 100 to 200 feet above the lake; and even 215 feet at Grand Haven, where, according to A. Winchell, the forest has been buried so as to leave only the "withered tree-tops projecting a few feet above the waste of sands." In Norfolk, England, between Hunstanton and Weybourne, the sands have traveled inland with great destructive effects, burying farms and houses. They reach, however, but a few miles from the coast line; and, were it not that the seashore itself is being undermined by the waves, and is thus moving landward, the effects would soon reach their limit.

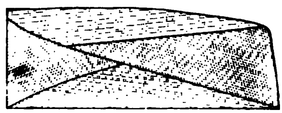
Dust is carried by storm winds, sometimes hundreds of miles. Dust from Africa has fallen on ships more than 1000 miles from the coast, and at points 1600 miles apart in a north and south direction (Darwin). Volcanic dust was carried in 1835 from Guatemala to Jamaica, 800 miles. In one dust shower, about Lyons in France, 720,000 pounds of dust fell; and of this 90,000 consisted of Diatoms and other organic relics (Ehrenberg).

would require winds without these irregularities, — little varying, and long continuing, — such as few regions have, except those that have winds of too moderate velocity to carry any but the finest particles. The gusty winds tend, by their denuding as well as transporting work, to make wavy rather than plane upper surfaces. Moreover, any barrier, as a projecting rock or ledge, or a stump, or group of trees, causes a heaping of the sands around the obstacle, and makes curving surfaces in the heaps, owing to the eddies that are made in the air.

On seashores the loose sands of the beach are driven inland by the winds, and thereby often form parallel ridges called dunes. They are grouped somewhat irregularly, owing to the course of the wind among them, and also to little inequalities of compactness, or to protection from vegetation. They form especially (1) where the sand is almost purely siliceous, and therefore only slightly adhesive even when wet, and not good for giving root to grasses; and (2) on windward coasts.

The stratification in such drift hills is of the kind represented in Fig. 161. Successive layers dip in various directions, and are abruptly cut short, showing that the growing hill was often partly cut down by storms, and was again and again completed after such disasters.

FIG. 161.



Irregular lamination in drifted sand.

On the southern shore of Long Island, series of such sand hills, 10 to 40 feet high, extend along for 100 miles. They are partially anchored by straggling tufts of grass. The coast southward to the Chesapeake is similarly fronted by sand hills. They occur also on the east coast of Lake Michigan, where some are 100 to 200 feet in height. In Norfolk, England, between Hunstanton and Weybourne, the sand hills are 50 to 60 feet high. In desert regions, the drifting of sand takes place on a far more extensive scale.

Drift hills of calcareous sand, from the disintegration of the locators of great forest regions and deserts, and the limiters of distribution for the living species of the land; and they have done their work essentially in the same way through all past time, and, in general, with like geographical effects over the same regions from one age to another.

IV. MECHANICAL EFFECTS OF WATER.

Water does mechanical work in the conditions of —

1. Fresh Water, or that of Rivers;
2. The Ocean;
3. Frozen Waters, or Glaciers and Icebergs.

1. Fresh Waters.

Sources of Rivers. — The water of rivers descends in the form of rain and snow from the clouds; and the clouds derive it, by evaporation, from the surface of the land, its soil, lakes, rivers, and foliage, and more abundantly from the ocean. The water rises in vapor into the upper regions of the atmosphere, and, becoming condensed into raindrops or snowflakes, falls over the hills and plains. The drops gather first into rills; these, as they descend, unite into rivulets; these, again, if the region is elevated or mountainous, into torrents; torrents, flowing down the different mountain valleys, combine with other torrents to form rivers; and rivers from one mountain chain sometimes join the rivers from another, and make a common stream of great magnitude and great drainage area, like the Mississippi or the Amazon.

The Mississippi has its tributaries among all the eastern heights of the great Rocky Mountain chain, throughout a distance of 1000 miles, or between the parallels of 35° N. and 50° N.; and another set of tributaries gather waters from the Appalachian chain, between western New York and Alabama. Rills, rivulets, torrents, and rivers com-

2. Winds as Transporters of Moisture.

The atmosphere takes moisture from the ocean and land, proportionally to its temperature, and transports it. If the air increases in temperature as it passes over a continent, it keeps taking up moisture, and so dries up the land; if, on the contrary, it loses in temperature, its capacity for moisture is lessened, and it drops it, making rain and mists over the land. If the warm wind strikes the cold side or summit of a mountain, the moisture is largely dropped, so that little remains for the region on the opposite side of the mountain, which therefore experiences drought.

The trade winds are movements of the air within the tropics, westward, against the east side of the continents; they are warm winds, well charged with moisture. Consequently, in those latitudes the eastern portions of continents are regions of much rain; and the farther back from the east coast the higher mountains are set, the larger the surface benefited by the rains. The position of the Andes, on the extreme western margin of South America, accordingly gives to nearly all the tropical portion of that continent an abundant rainfall, making it the greatest forest region of the globe.

The prevailing winds in middle latitudes, on the other hand, move eastward, being southwest winds in the northern hemisphere, and northwest winds in the southern hemisphere. The great warm-water area of the Gulf of Mexico is thus of immense service to eastern North America, furnishing to the southwest winds the abundant water supply which makes the eastern half of the continent a region of moist climate and abundant forests.

The arid climate of the Great Basin and much of the eastern slope of the Rocky Mountains, and that of the coast of Peru and the plains of southern Argentina, illustrate the other side of the working of the same laws.

Thus the winds are largely the distributors of fertility, respecting falling bodies, the energy should vary as the product of volume and height of fall. This working power is expended in friction, between the water and the bed of the water way, between the water and the atmosphere, and between the molecules of the water itself: and in transportation of rock material (which must meanwhile be supported in opposition to gravitation). In these ways, the energy of a stream is generally so far used up that it has very little velocity as it approaches its outlet.

Kinds of Work.—The kinds of work done by streams are the following:—

1. *Transportation* of earth and stones, and often also of logs and leaves, for deposition down stream.

2. *Excavation* of a waterway, by the impact of the moving water, and by that of the transported stones and earth.

3. *Mutual abrasion* of the transported stones and earthy particles, reducing them in size, and rendering them thereby easier to transport.

The action of running waters in wearing down the elevated portions of the earth's surface toward sea level is called denudation, or degradation.

Nearly all valleys of the world owe their formation in large degree to excavation by running water. Even valleys which had their origin in differential elevation of the earth's crust, have been considerably modified by river erosion.

DENUDATION.

Causes and Conditions influencing Denudation. — Denudation is carried on chiefly by the process of abrasion. Direct blows of the water are efficient in rapid, plunging streams, especially where the rocks are much jointed, fissile, or fragile, and where cavities or recesses exist to receive the blows; but over firm rocks of flat or convex surface they have little effect. Blows of solid material, as grains of sand or stones, are more effective than those of water. Hence, up to a certain limit, abrasion is increased by the load of sediment which the stream is carrying. Beyond that limit, however, the load of sediment so far diminishes the velocity of the stream as to diminish or entirely abolish its power of erosion.

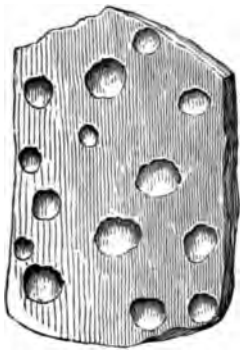
Moreover, the decomposing and dissolving action of water and other agencies gives important aid in the work of denudation. Decomposition and disintegration (pages 111–115) are going on over almost all exposed surfaces of rocks, thus making softened material for the abrading and transporting rills and rivers. Solution also has considerable effect, especially in limestone regions; it helps much in the excavation of valleys, and finds in the joints of the rocks a chance to begin the work (page 144).

The rounded stones, gravel, and earth of fields, and also the material of most geological formations, have been made to a large degree by the wearing action of waters — either those of streams over the land, or those of the ocean. But this action is, and ever has been, greatly aided by the processes of decomposition and disaggregation due to the elements — causes that are sufficient alone to turn angular blocks of most rocks into rounded masses.

Rivers do the chief part of their work in times of floods. Many a torrent is a quiet brook at other seasons, or perhaps only a string of pools. At low water the pitch of the stream, or that of its upper surface, is at its minimum, while the ratio of friction to the amount of water is at a maximum, so that the water often lies almost still between its banks. But at flood height the pitch is increased, and the friction relatively decreased; and hence comes the flood velocity. The Connecticut, from Hartford to the Sound, 36 miles (in an air line), is a tidal stream, zero in working force, at low tide and low water; but, in its highest flood (30 feet at Hartford), it has a mean pitch of 10 inches a mile, and flows off with great rapidity. On mountain streams the transition is often from almost or quite zero to a succession of cataracts of vast working force.

Work of Denudation. — Denudation commences with the raindrop; for a shower of rain consists of an infinitude of little waterfalls, each having power to denude by stripping off grains from the surface of soft or weathered rocks, and to excavate where it falls on a mud flat or sand flat recently laid bare (as by the ebb of the tide), and make the raindrop impression. The quick succession of drops ordinarily obliterates the special work of each; but, in a shower of large drops and short duration, they remain, so that rain prints (Fig. 162) are not uncommon markings on the surface of strata.

Fig. 162.



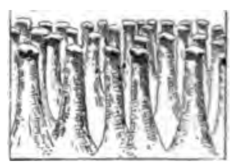
Rain prints.

The next sweep of the waters over the surface may fill the cavities with fine mud or sand, and so they may become buried records.

A wind may give the drops greater efficiency in abrasion. At the same time it may register its direction in the elliptical form of the rain prints.

When the drops strike a gravel bed, stones in the gravel may protect the material directly beneath, while the surrounding material is eroded. Thus slender columns are left, each capped with a pebble or bowlder.

Fig. 163.



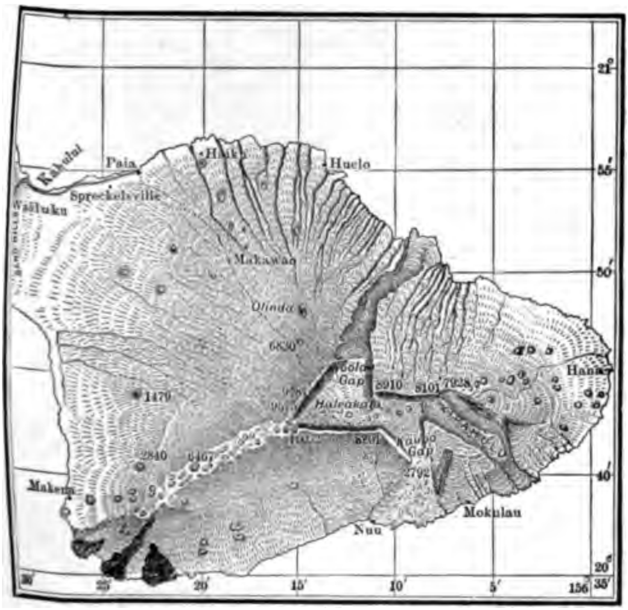
Drop-made columns, natural size.

Fig. 163 shows a miniature example of this phenomenon. It was observed by the author in 1887, near the path which leads down to the bottom of the crater of Kilauea, on the Island of Hawaii. The drops had fallen from shrubbery, wet by the heavy mist condensed from the steam of the volcano. In other localities, columns scores of feet in height have been carved by raindrops in glacial drift and similar materials.

The raindrops make rills and rivulets; and these, as they hurry on their way, carry off light earth or sand, and so make channels and deepen their beds. This may be well seen along many a roadside, or over sand banks during and after a shower.

Torrents, from combined rivulets, work with greater power, tearing up rocks and trees as they plunge along,

FIG. 164.



Eastern part of the Island of Maui, Hawaiian Islands.

and, in the course of time, making deep gorges or valleys in the mountain slopes; and rivers, when in full action, work with vast power, making wide valleys over the breadth of the continent. The slopes of a lofty mountain, exposed through ages to the action described, finally become reduced to a series of valleys and ridges, with towering peaks and crested heights — all these effects originating in the fall of raindrops or snowflakes.

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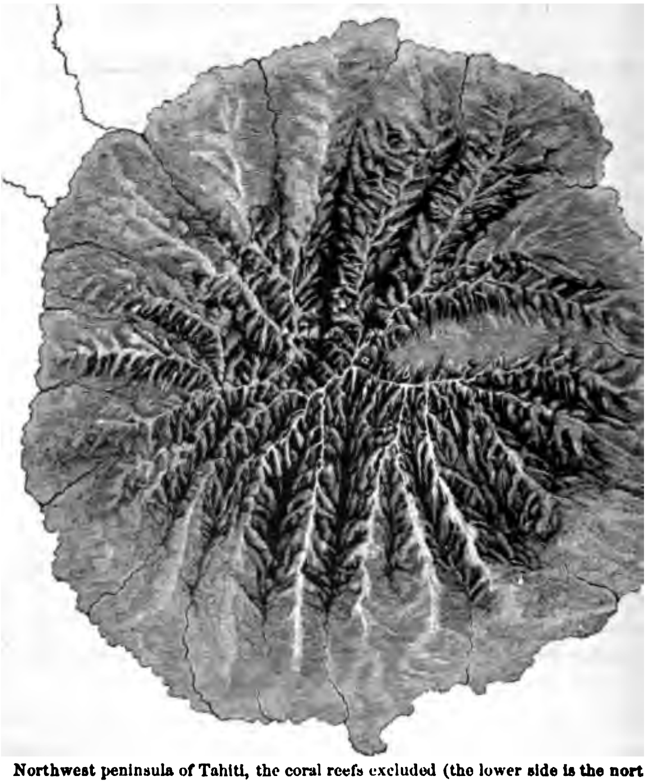
FIG. 165.



Northwest peninsula of Tahiti, the coral reefs excluded (the lower side is the nort

Mauna Loa, on the Island of Hawaii (see map, Fig. page 179). Denudation has its chance only after th canic activity has begun to decline. The waters o rains (which are always most copious about the sun of high mountains), beginning in rivulets down the sl first gather sufficient strength for effective denudation toward the base of the mountain.

In the eastern volcanic cone of Maui (see map, Fig. 164), the process of valley-making has commenced. The channels of the rivers of the north side, as the map indicates, extend only halfway up the mountain; on the northeast, or the most rainy side, they extend up to a level just below the summit; while on the west side, they are merely narrow trenches, and are dry through nearly all the year. The last eruption of the volcano took place, according to tradition, about 250 years since.

Fig. 165 represents the topography of the northwest peninsula of Tahiti, one of the Society Islands. The volcano has been long extinct — long enough for the extension of the river channels to the summit, and for the continued excavation of these channels until they have become valleys 1000 to 3000 feet deep, with spacious amphitheaters, or cirques, at their head, reducing the island to a group of knife-edge ridges and steep-sided gorges. The highest peaks (*a* and *b* on the map) are parts of the narrow ridges thinned down to a breadth at top of one to ten feet, while 8000 and 7000 feet in altitude. They face with a nearly vertical front, at one point at least 4000 feet high, two of the grandest of the amphitheaters. The amphitheaters, or cirques, are made by water alone, in a tropical region, and show that the help of glaciers is not required, as sometimes supposed, for such results.

Forms of Valleys; Channels and Flood Grounds of Rivers. — The valleys excavated by mountain streams have a V-shaped cross section. But, when the river flows into a region of gentle declivities or plains, the waters lose in velocity, and may even deposit sediment over the bed, instead of deepening it by excavation. At the same time, the waters, no longer able to deepen their channel, begin to erode laterally, undermining their banks, and making a flood plain, over which the waters spread in their annual or occasional freshets.

Nearly all streams over the plains and lower slopes of the land have narrow channels for dry times, and flood grounds which they cover in times of great rains or melting snows. The alluvial plains of rivers are, in part, these plains formed by lateral erosion, but covered by deposits left by the flooded stream; in part, areas reclaimed from sea or lake, as in the formation of deltas (pages 138–140).

FIG. 166.

Marble Cañon, Colorado River.

Cascades. — Cascades are often formed where, in the course of a rapid stream, there are alternations of hard and soft rocks. The hard rocks resist wear, while the soft ones easily yield; and thus a plunge begins, which increases in force as it increases in extent. Rills and rivulets made by a shower of rain along roadsides or sand banks often illustrate this feature of great mountain streams.

Cañons.—When a region has been recently elevated to a high altitude, giving the streams power for rapid erosion, especially if the rocks are nearly horizontal, the valleys cut by the rivers have usually bold rocky sides. In many parts of the Rocky Mountains, the streams have worked their way down through the rocks for hundreds, and in some places even thousands, of feet. Such a valley is called a cañon.

These cañons have great depth and magnitude on the Colorado River, over the west slope of the Rocky Mountains, between longitude 111° W. and 115° W. For more than 300 miles there is a nearly continuous cañon, 3000 to 6000 feet deep. The preceding sketch, from one of the excellent photographs of the region by the artist of Powell's Expedition, represents a portion of it, called the Marble Cañon. The rocks stand in nearly vertical precipices on either side of the stream, and the height above the water to the top of the bluff seen in the distance is 5000 feet. The deep gorge is the result of erosion by the stream.

Fig. 167 presents a view of another part of the cañon, and shows better the details of the stratification in its lofty walls.

In many places, the wall of the cañon is carved into alcoves and buttresses in infinite variety. Some of the larger projecting masses imitate on a colossal scale the forms of oriental temples. All these picturesque features are the work of the sculpturing waters since the time of the early Tertiary. Moreover, over the country to the northward, rise plateaus and mountains, in which the strata are piled up to an additional altitude of 5000 to 7000 feet, and these are portions of great formations that once spread across the whole region.

Sculpture of Mountain Forms; Mountains of Circumdenudation. — Given a great elevated plateau in a region of rains, and mountain sculpturing will go on about it, and continue until all is ridge and valley, not a square mile of the original plateau retaining its flat surface; and the resulting crested ridges may rise thousands of feet above the bottoms of the valleys, if the plateau was one of sufficient height. The Catskill Mountains, New York, are an example of mountains of circumdenudation.

FIG. 167.

Wall of Colorado Cañon.

The following figures, by Lesley, illustrate some of the results of sculpturing by water, in both horizontal and upturned or flexed strata. In the production of such erosion forms, the ocean has sometimes taken part during the submergence of a continent; but the final results are, in almost all cases, due to the chiselings of fresh waters. The figures here given are small, but the elevations they represent, as illustrated in the Appalachians, Jura, and many other mountain regions, are often thousands of feet in height.

When the beds are horizontal, or nearly so, but of unequal hardness, the softer strata are easily worn away, and by this means the harder strata become undermined. Table-

Fig. 168.

Fig. 169.

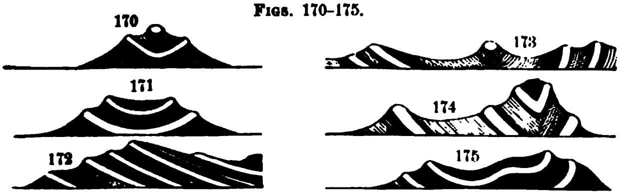
Erosion forms in nearly horizontal strata.

shaped mountains are often thus formed, having a top of the harder rock, and the declivities banded with projecting shelves and intervening slopes. Figs. 168, 169 represent the common character of such hills. Such flat-topped elevations in the Colorado region have been called mesas, from the Spanish for table.

When the beds are inclined between 5° and 30°, there is a tendency to make hills with a long back slope and bold front; but, with a much larger dip, the ridges are more nearly symmetrical.

When the dipping strata are of unequal hardness, and

Figs. 170–175.



Erosion forms in synclinal strata.

lie in folds, there is a wide diversity in the results on the features of the landscape.

Figs. 170–175 represent the effects from the erosion of a synclinal region consisting of alternations of hard and soft rocks. The protection of the softer beds by the harder is well shown.

Anticlinal strata give rise to another series of form in part the reverse of the preceding, and equally varied Figs. 176–179 represent some of the simpler cases. Whe the back of an anticlinal mountain is divided (as in Figs 176–178), the mountain apparently loses the anticlina

Figs. 176-179.

Erosion forms in anticlinal strata.

character, and the parts are, in aspect, simply monoclina ridges. In Fig. 179 the anticlinal character is distinct i the central portion, while lost in the parts on either side In Fig. 179, to the right, the protection afforded to softe strata by even a vertical stratum of hard rock is illus trated: the vertical stratum forms the axis of a lo ridge.

TRANSPORTATION AND DEPOSITION.

Fact of Transportation. — It has been stated that th massive mountains have been eroded into ridges and val leys by running water. The material worn out has bee transported somewhere by the same waters.

Part of the transported material in all such operation goes to form the great alluvial plains that occupy th river valleys, especially in the lower part of their course Part is carried to the sea into which the river empties where it meets the counteracting waves and currents, an is distributed for the most part along the shores, fillin estuaries or bays, or making deltas, and extending th bounds of the lands; or to lakes, with or without outlets

The mountains of a continent are ever on the mov seaward, and thus contribute to the enlargement of th seashore plains. The continent is losing annually in mea height, but gaining in width, or extent of dry land.

Transporting Power of Water. — The transporting power of running water is very great when the flow is rapid. Large stones and masses of rock are torn up and moved onward by the mountain torrent. A current of four miles an hour will carry stones $2\frac{1}{3}$ inches in diameter; of two miles, pebbles of 0.6 inch; of two thirds of a mile, fine sand, about .064 inch in diameter; of one third of a mile, fine earth or clay, the particles .016 inch in diameter; the mean diameter of the largest transportable particles varying as the square of the velocity, supposing them of like density.

Hence, as a stream loses in velocity, it leaves behind the coarser material, and carries only the finer; if the rate becomes very slow, it drops the gravel or the sand, and bears on only the finest earth or clay. Consequently, where the current is swift, the bottom (if not consisting of rocky ledges) is stony or pebbly; and where the water is still, or nearly so, the bottom is muddy. Slow rivers and small lakes have commonly muddy borders.

Amount of Material Transported.—The amount of transported material varies with the size and current of the rivers and the kind of country they flow through. The Mississippi carries annually to the Gulf of Mexico, according to Humphreys and Abbot, on an average, 812,500,000,000 pounds of silt — equal to a mass one square mile in area and 241 feet deep, — and its bottom waters push on enough more to make the 241 feet 268 feet. The process slowly lowers the drainage area of the river, and the mean amount of lowering indicated by the facts stated is one foot in 4920 years. The total annual discharge of silt by the Ganges has been estimated at 6,368,000,000 cubic feet.

Besides the silt, rivers carry what the waters take into solution. The amount is generally between a third and a half of that mechanically transported; but sometimes nearly an equal weight. If one half, in the case of the Mississippi, the period of 4920 years would be reduced to

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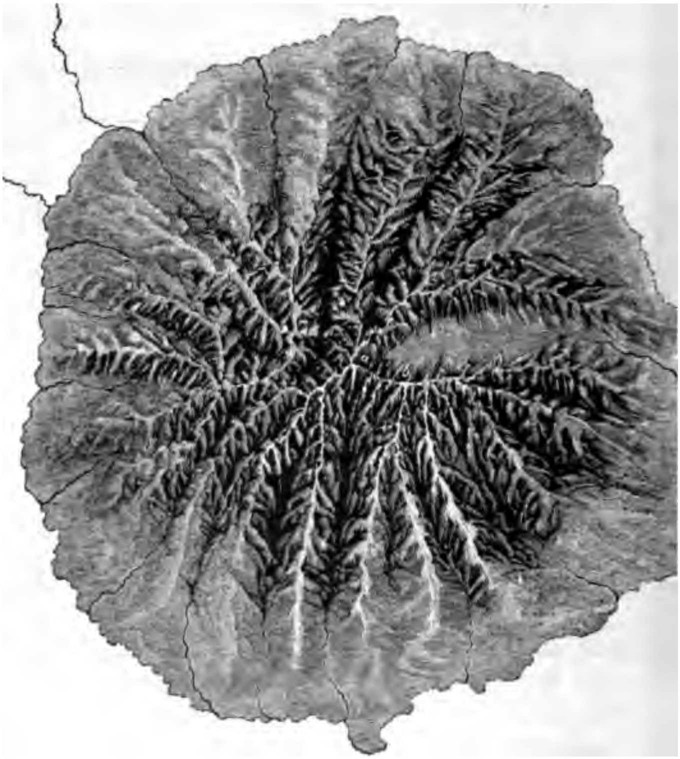

Northwest peninsula of Tahiti, the coral reefs excluded (the lower side is the northern

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These cañons have great depth and magnitude on the Colorado River, over the west slope of the Rocky Mountains, between longitude 111° W. and 115° W. For more than 300 miles there is a nearly continuous cañon, 3000 to 6000 feet deep. The preceding sketch, from one of the excellent photographs of the region by the artist of Powell's Expedition, represents a portion of it, called the Marble Cañon. The rocks stand in nearly vertical precipices on either side of the stream, and the height above the water to the top of the bluff seen in the distance is 5000 feet. The deep gorge is the result of erosion by the stream.

Fig. 167 presents a view of another part of the cañon, and shows better the details of the stratification in its lofty walls.

In many places, the wall of the cañon is carved into alcoves and buttresses in infinite variety. Some of the larger projecting masses imitate on a colossal scale the forms of oriental temples. All these picturesque features are the work of the sculpturing waters since the time of the early Tertiary. Moreover, over the country to the northward, rise plateaus and mountains, in which the strata are piled up to an additional altitude of 5000 to 7000 feet, and these are portions of great formations that once spread across the whole region.

Sculpture of Mountain Forms; Mountains of Circumdenudation. — Given a great elevated plateau in a region of rains, and mountain sculpturing will go on about it, and continue until all is ridge and valley, not a square mile of the original plateau retaining its flat surface; and the resulting crested ridges may rise thousands of feet above the bottoms of the valleys, if the plateau was one of sufficient height. The Catskill Mountains, New York, are an example of mountains of circumdenudation.

Fig. 167.

Wall of Colorado Cañon.

The following figures, by Lesley, illustrate some of the results of sculpturing by water, in both horizontal and upturned or flexed strata. In the production of such erosion forms, the ocean has sometimes taken part during the submergence of a continent; but the final results are, in almost all cases, due to the chiselings of fresh waters. The figures here given are small, but the elevations they represent, as illustrated in the Appalachians, Jura, and many other mountain regions, are often thousands of feet in height.

When the beds are horizontal, or nearly so, but of unequal hardness, the softer strata are easily worn away, and by this means the harder strata become undermined. Table-

Fig. 168.

Fig. 169.

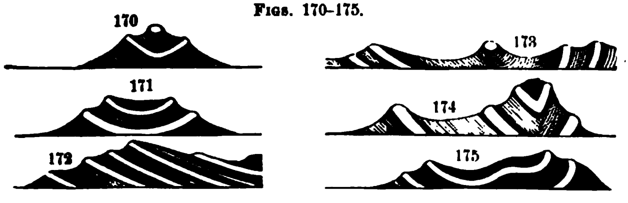
Erosion forms in nearly horizontal strata.

shaped mountains are often thus formed, having a top of the harder rock, and the declivities banded with projecting shelves and intervening slopes. Figs. 168, 169 represent the common character of such hills. Such flat-topped elevations in the Colorado region have been called mesas, from the Spanish for table.

When the beds are inclined between 5° and 30°, there is a tendency to make hills with a long back slope and bold front; but, with a much larger dip, the ridges are more nearly symmetrical.

When the dipping strata are of unequal hardness, and

Figs. 170–175.



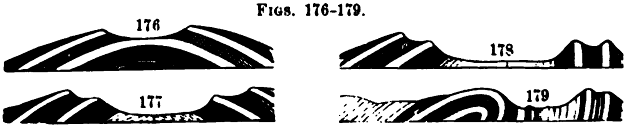
Erosion forms in synclinal strata.

lie in folds, there is a wide diversity in the results on the features of the landscape.

Figs. 170–175 represent the effects from the erosion of a synclinal region consisting of alternations of hard and soft rocks. The protection of the softer beds by the harder is well shown.

Anticlinal strata give rise to another series of forms, in part the reverse of the preceding, and equally varied. Figs. 176–179 represent some of the simpler cases. When the back of an anticlinal mountain is divided (as in Figs. 176–178), the mountain apparently loses the anticlinal

FIGS. 176-179.



Erosion forms in anticlinal strata.

character, and the parts are, in aspect, simply monoclinal ridges. In Fig. 179 the anticlinal character is distinct in the central portion, while lost in the parts on either side. In Fig. 179, to the right, the protection afforded to softer strata by even a vertical stratum of hard rock is illustrated: the vertical stratum forms the axis of a low ridge.

TRANSPORTATION AND DEPOSITION.

Fact of Transportation. — It has been stated that the massive mountains have been eroded into ridges and valleys by running water. The material worn out has been transported somewhere by the same waters.

Part of the transported material in all such operations goes to form the great alluvial plains that occupy the river valleys, especially in the lower part of their course. Part is carried to the sea into which the river empties, where it meets the counteracting waves and currents, and is distributed for the most part along the shores, filling estuaries or bays, or making deltas, and extending the bounds of the lands; or to lakes, with or without outlets.

The mountains of a continent are ever on the move seaward, and thus contribute to the enlargement of the seashore plains. The continent is losing annually in mean height, but gaining in width, or extent of dry land.

Transporting Power of Water. — The transporting power of running water is very great when the flow is rapid. Large stones and masses of rock are torn up and moved onward by the mountain torrent. A current of four miles an hour will carry stones $2\frac{1}{8}$ inches in diameter; of two miles, pebbles of 0.6 inch; of two thirds of a mile, fine sand, about .064 inch in diameter; of one third of a mile, fine earth or clay, the particles .016 inch in diameter; the mean diameter of the largest transportable particles varying as the square of the velocity, supposing them of like density.

Hence, as a stream loses in velocity, it leaves behind the coarser material, and carries only the finer; if the rate becomes very slow, it drops the gravel or the sand, and bears on only the finest earth or clay. Consequently, where the current is swift, the bottom (if not consisting of rocky ledges) is stony or pebbly; and where the water is still, or nearly so, the bottom is muddy. Slow rivers and small lakes have commonly muddy borders.

Amount of Material Transported. — The amount of transported material varies with the size and current of the rivers and the kind of country they flow through. The Mississippi carries annually to the Gulf of Mexico, according to Humphreys and Abbot, on an average, 812,500,000,000 pounds of silt — equal to a mass one square mile in area and 241 feet deep, — and its bottom waters push on enough more to make the 241 feet 268 feet. The process slowly lowers the drainage area of the river, and the mean amount of lowering indicated by the facts stated is one foot in 4920 years. The total annual discharge of silt by the Ganges has been estimated at 6,368,000,000 cubic feet.

Besides the silt, rivers carry what the waters take into solution. The amount is generally between a third and a half of that mechanically transported; but sometimes nearly an equal weight. If one half, in the case of the Mississippi, the period of 4920 years would be reduced to

3280. The salts held in solution are often about one half calcium carbonate, and the rest calcium sulphate, sodium chloride (common salt), sodium carbonate, and magnesian and potash salts, with traces of silica and other ingredients. In some cases the rivers carry the salts to inland seas or lakes, which have no drainage toward the ocean, and which therefore are saline (page 117). Moreover, arid plains become saline because of the capillary action which brings moisture from below to the surface, as evaporation goes on above, depositing the contained saline ingredients, such as the sodium chloride, sodium carbonate, and magnesian salts of such places.

Alluvial or Fluvial Formations. — The deposits made by the transported material, which now constitute the alluvial plains of the river valleys, cover a large part of a continent, since rivers or smaller streams are almost everywhere at work. They are made up of layers of pebbles or gravel, and of earth, silt, or clay, especially of these finer materials. Logs, leaves, shells, and bones occur in them: but these are rare; for whatever floats down stream is widely scattered by the waters, and to a great extent destroyed by wear and decay. The level of the alluvial plain is ordinarily about that of the level of the higher floods. The spreading waters, by here losing their velocity, owing to friction, build up the deposits. The river margin is often a little above flood level, owing to the shrubbery growing along it, and to the abundant deposit of sediment where the water flowing outward from the channel onto the flood plain, receives the first check to its velocity.

Terraces. — River valley or fluvial formations often have the form of terraces. Terraces are in general remnants of old flood plains, the rivers having deepened their channels on account of elevation of the land; and seashore flats and beaches, and horizontal lines of wave erosion on cliffs, have often been left high in the same movements.

Estuary and Delta Formations.—The detritus discharged by the river at its mouth tends to fill up the bay into which it empties, and make wide flats on its borders, and thus contract it to the breadth merely of the river current.

Fig. 180.

Delta of the Mississippi.

Where the tides are feeble and the river large, the deposits about the mouth of the stream gradually encroach on the ocean, and make great plains and marshy flats, which are intersected by the many mouths of the river and a network of cross channels. Such a formation is called a delta. Fig. 180 represents the delta of the Mississippi, the white lines being the water channels, and the black areas the great alluvial plains. The delta properly commences below the mouth of Red River, where the Atchafalaya Bayou, or side channel of the river, begins. The whole area is about 12,300 square miles; about one third is a sea marsh, only two thirds lying above the level of the gulf.

The deltas of the Nile and the Ganges are similar in general features to the delta of the Mississippi.

The detritus poured into the ocean where the tides or currents are strong, and a considerable part of that where the tides are feeble, goes to form seashore flats and sand banks and offshore deposits. In their formation the ocean takes part through its waves and currents, and hence they are more conveniently described in connection with the remarks on the work of the ocean.

HISTORY OF RIVERS.

Youth and Old Age of Rivers. — The work of excavation tends toward the lowering of the bed of a stream to the sea level. The process involves the wearing away of waterfalls and rapids; the draining of the lakes along the river course, as far as these have their beds above sea level; and the filling up of lake basins, even those that descend below that level. Reducing the slope of the bed deprives the waters of working power, and finally the stage is reached when abrasion and deposition over the bed balance each other. Thus rivers pass from youth to old age.

The condition of balance between erosion and deposition has been called by Powell the condition of ***base level;*** and he has formulated the important general law that a river always works toward its base level, eroding its bed when it is too high, and filling it up when it is too low.

When the river ends in a lake without outlet, the process terminates at the lake, but is otherwise the same as above described.

The history of a river is often modified by continental changes of level. An elevation may rejuvenate streams that are approaching old age, or a subsidence may bring the streams to a premature old age.

In a region which has undergone subsidence, the lower part of a river's course may be below base level. In that case, deposition will be in excess, and the level of the bed will be annually raised. Consequently, during floods, the waters along the region of the shallowed channel will spread more and more widely, as the years pass, over the country either side, with disastrous encroachments on forests and whatever is in their way. Man, to protect his buildings and cultivated fields, raises the banks, or builds dikes or levees along them; but the waters cannot be crowded, and at intervals they sweep away the confining levees, to the confusion of the dwellers on the "recovered" lands.

Again, the extraordinary floods of a Glacial period have given temporary increase of vigor to enfeebled rivers.

Moreover, changes of level have sometimes joined the head of one stream to the trunk of another; or made a northward-flowing stream of one that had previously flowed southward; or converted a region of once active rivers into a vast lake. Rivers were few and small when lands were small; and multiplied and extended and finally became combined into great drainage systems, with the growth and completion of the continents.

The effect of the long work of the waters over the land is the gradual degradation of the hills and mountains, reducing great regions to approximately level plains — *peneplains* (from the Latin *pene*, almost, and *planum*, plain), as they have been called by W. M. Davis; and finally, in theory at least, the reduction of the whole continent to the condition of a base-level plain.

Cause of Direction of Flow. — The simple explanation of the direction of flow in a river is that it was determined by the slope of the land. But in many cases the course is due not to the present slopes and conditions, but to others that existed at some earlier time. The working waters have sometimes started on their way to the sea, when the topography was very different from the present; and they have kept their old course in spite of such obstacles as folds or faults developed transversely to their course. Such drainage has been called by Powell *antecedent* drainage; and that which is a consequence of existing conditions, *consequent* drainage. When a stream has cut through the entire thickness of the formation upon which it commenced, and is flowing now in unconformably underlying rocks, without regard to their structure, the drainage is said to be *superimposed*.

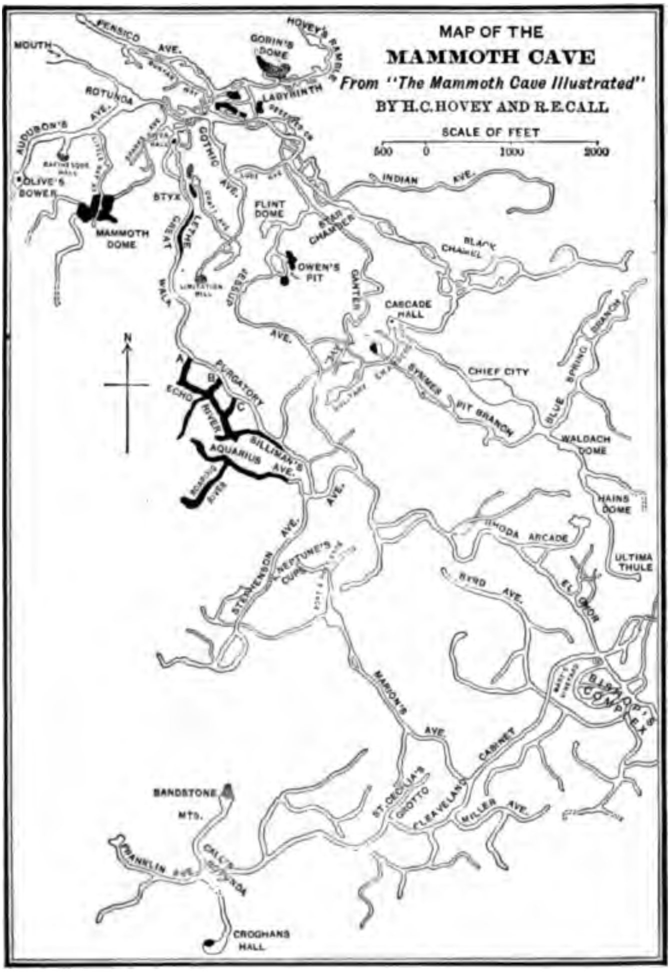
SUBTERRANEAN WATERS.

Origin and Course of Subterranean Waters. — A part of the water that falls on the earth's surface — on its mountains as well as its plains — sinks through the ground and into the rocks beneath, wherever there are openings or crevices, or looseness of texture, and thus becomes subterranean. The waters usually pass easily through sandstones; but over a clayey or other compact stratum they accumulate, and often make wet, springy soil above; or, if the stratum is inclined, they may descend to great depths, or come to light again wherever it outcrops at a lower level. The descending waters sometimes gather into subterranean streams, which have powers of abrasion. Over large areas in some limestone regions, and in many volcanic regions, surface streams are wanting, because of the cavernous recesses; the waters carry on an underground system of drainage. Thus come springs, subterranean streams large and small, and copious outflows beneath the sea level along coasts.

[redacted]

A region of horizontal limestone abounds in sink-holes, as well as caverns; and sometimes rivers plunge down the openings into the recesses below, and are lost, or emerge again in fuller flow a mile or more away.

FIG. 181.



Ordinary waters easily erode limestone, because they contain carbonic acid (page 115). Through the joints or fissures the waters find a way downward, and the erosion they produce widens the joints, often forming funnel-shaped sink-holes. At the bottom of the sink-hole the waters work laterally, eroding channels and chambers, in long series and varying directions; and if, later, they succeed in penetrating to a still lower level, another tier of chambers is begun. Undermining also goes on, causing falls of rock, which are sometimes large enough to make feeble earthquakes. Occasionally some part of the roof caves in, and the cavern, with the river inclosed, becomes open to the light, and thus affords an example of one method of making limestone gorges.

The preceding map (modified from Hovey's "Celebrated American Caverns," with additions by R. E. Call) shows the passages and chambers of Mammoth Cave, Kentucky. This cave occupies an area of several square miles in the Subcarboniferous limestone. The length of the caverns in this limestone in Kentucky (a rock 200 to 1000 feet thick) is estimated by Professor Shaler at 100,000 miles. Luray Cavern, in Luray Valley, Virginia, is comparatively small; but, as described by Mr. Hovey, it is one of the most remarkable in the world, for the beauty of its stalactitic hangings and the grandeur of its subterranean chambers.

In many caverns, bones of the animals that have inhabited them, including sometimes those of Man, with his implements of stone or shell or other material, are found buried beneath or within the stalagmite that covers the floor — the perpetual dripping keeping up its constant deposition (pages 40, 115).

Caves exist in the elevated coral reefs of the Pacific, which are certainly of comparatively recent origin. One, on the island of Atiu, near Tahiti, has "interminable windings" and many chambers, "with fretwork ceilings of stalactite" (J. Williams). There are others on Oahu, which give a passage to streams.

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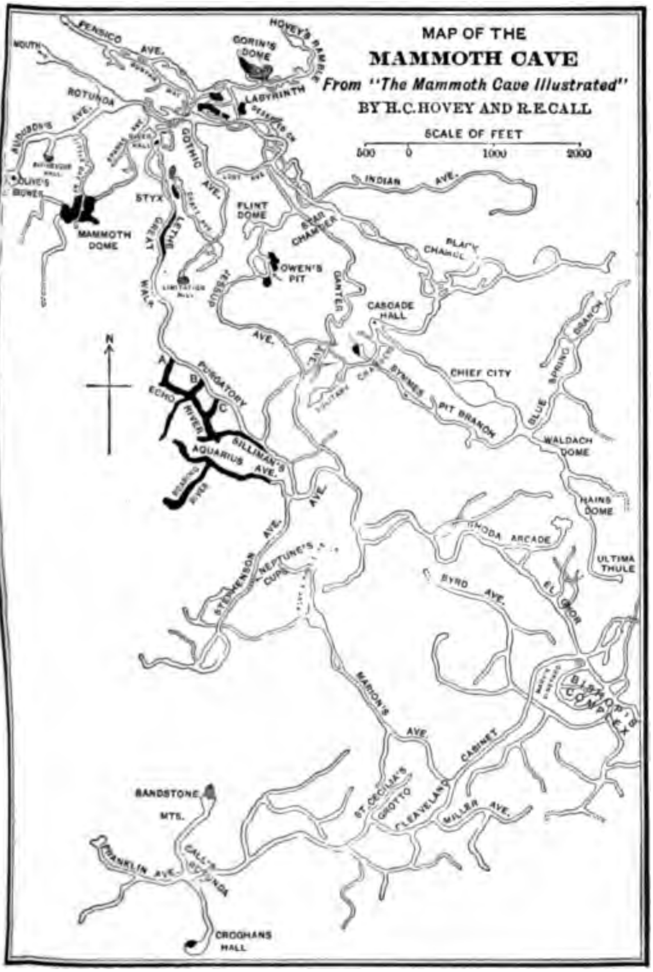

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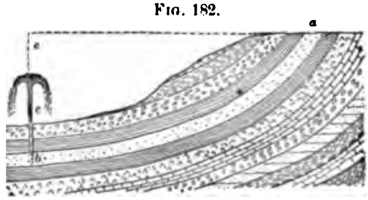
The erosion may be helped forward (1) by the oxidation of pyrite (page 112) where it is present, the resulting sulphuric acid turning limestone into gypsum; and also (2) by the formation of nitric acid (probably from the nitrogen of the air, by means of micro-organisms), which corrodes the limestone, making calcium nitrate. The caves of Kentucky and Indiana have afforded a large amount of this nitrate for the making of niter.

Subterranean waters often become mineral waters. They are made calcareous by limestones along their course; saline, by the saline ingredients of rocks; sulphurous, by decomposing iron sulphides; carbonated, by any acid, as sulphuric, attacking a limestone and setting carbonic acid free; chalybeate, by the reduction of ferric oxide in presence of organic matters, and the formation of ferrous bicarbonate; magnesian, by the decomposition of minerals containing magnesium. They may become warm waters through subterranean heat, and may receive vapors and various mineral materials from the depths below.

Artesian Wells.—When strata are inclined, and water descends along one of the layers between others that are sufficiently impervious to confine it, the pressure increases with the depth; so that the water will rise through a boring made down to it, and sometimes in a high jet. The principle is illustrated in Fig. 182, in which *ab* is the water-bearing stratum, *bc* the boring, and *eb* the amount of descent. The height of the jet falls much short of *be*, chiefly on account of the underground friction.

Fig. 182.



Section illustrating Artesian wells.

Such wells are called Artesian wells or borings, from the district of Artois in France, where they were early made. The Artesian well of Grenelle in Paris is 1798 feet deep, Sound, along which the inflowing tide moves westward, well illustrate these facts. The two largest of the rivers, the Connecticut and Housatonic, are of the unfortunate kind, as they have no eastern cape; while the harbor of New Haven, although it receives only very small streams, is much better off, as regards depth of water for entrance, because of a projecting eastern cape.

The bore, or eager, of some great rivers is a kind of tidal flow up a stream. It is produced when the regular rise of the tide in the bay at the mouth of the river is obstructed by the form of the entrance and its sand banks, together with the outflow of the river, so that the waters are for a while prevented from entering, until, finally, all those of one tide rush in at once, or in a few great waves. The eagers of the Amazon, the Hoogly in India (one of the mouths of the Ganges), and the Tsien-tang in China, are among the most remarkable. In the case of the Tsien-tang, the water moves up stream in one great wave, plunging like an advancing cataract, four or five miles broad and 30 feet high, at a rate of 25 miles an hour. The boats in the middle of the stream simply rise and fall with the passage of the wave, being pushed forward only a short distance; but along the shores there is often great devastation, the banks being worn away, and animals sometimes surprised and destroyed.

3. **Currents made by Winds.** — The great currents of the ocean, such as the Gulf Stream, are attributed by most physicists to this source. But, besides these, there are local currents along many coasts produced by winds, especially when there are long and violent storms, or winds blowing for months in one direction. Such currents, sweeping by a coast, transport from one place to another in their course more or less of the sand of the shores, often making long sand flats or spits off the shores to leeward, as on the south coast of Long Island and along the more southern parts of the Atlantic border. The action is aided by the tidal currents. In some cases the drifted

The saltness of the ocean gives it a density of 1.0240 to 1.0278, that of pure fresh water being 1. It is slightly the greatest in the tropics, because of the evaporation. A cubic foot weighs about 64 pounds. There are three consequences of the saltness: — (1) slightly greater transporting power than fresh water, on account of its density; (2) much quicker deposition of the finest sediment, the salt causing a flocculation and rapid precipitation of minute clayey particles, which in pure water remain in suspension for an indefinite period; (3) a supply of common salt and magnesian salts, etc., for making deposits of salts, and for use in chemical changes attending the making of rocks and minerals, the ocean being, so to speak, the largest of mineral springs.

The mechanical effects of the ocean are produced by its waves and currents.

EROSION AND TRANSPORTATION.

1. **Waves.** — *General Action.* — The force in oceanic waves is a constant force. Night and day, year in and year out, with hardly an intermission, they break against the beaches and rocks of the coast; sometimes gently, sometimes in heavy plunges that have the force of a Niagara of almost unlimited breadth. The gentlest movements have some grinding action among the sands, while the heaviest may dislodge and move along, up the shores, rocks many tons in weight. Niagara wastes its power by falling into an abyss of waters; but in the case of the waves the rocks are bared anew for each successive plunge. The waters are often loaded with gravel and sand when they strike, and thus carry on abrasion. Cliffs are undermined, rocks are worn to pebbles and sand, and, through mutual friction, sand is ground to the finest powder. Rocky headlands on windward coasts are especially exposed to wear, since they are open to the battering force from different directions.

tus brought down by rivers and poured into the ocean, as explained on pages 136–140.

The latter, in the present age, is by far the more important. But in the earlier geological ages, when the dry land was of small extent, rivers were small and were but a feeble agency.

The decomposition or disintegration of exposed rocks through the agency of air and moisture must have aided in degradation formerly more than now, since, in Paleozoic time and earlier, carbonic acid, the chief agent of destruction, was much more abundant in the atmosphere than it is now. This agent is carried to the earth's surface by the rains, and it is still effective in the decomposition of granite, gneiss, and many other rocks. The higher temperature of the atmosphere in early geological times was also favorable to rapid chemical action.

Forces in Action. — In the distribution of the material, the waves and marine currents have either worked alone, in the manner explained on the preceding pages, or in conjunction with river currents wherever these existed.

Marine Formations. — The marine formations are of the following kinds: —

1. *Beach Accumulations.* — Beaches are made of the material borne up the shores by the waves and tides and left above low-tide level. This material consists of stones or pebbles, sand, mud, earth, or clay. It is coarse where the waves break heavily, because, although trituration to powder is going on at all times, the powerful wave action and the undercurrent carry off the finer material into the offshore shallow waters, where it settles over the bottom or is distributed by currents. It is fine where the waves are gentle in movement, as in sheltered bays, or estuaries, the triturated material remaining in such places near where it is made, and often being the finest of mud.

2. *Sand Banks, or Reefs; Shallow-water Accumulations.* — Shallow-water accumulations may be produced in bays, estuaries, or the inner channels of a coast, and over the

sand may be in part carried back again when the season changes to that in which the wind blows from the opposite direction. Other portions of detritus may be carried away from the land and distributed in the deeper waters.

The great currents of the ocean are for the most part so distant from the borders of the continents that little detritus comes within their reach. As these currents have great depth — often a thousand feet or more, — their course is determined partly by the deep-water slopes of the submerged border of a continent, so that, when the border is shallow for a long distance out (as off New Jersey and Virginia, where this distance is even 50 to 80 miles), the main body of the current is equally remote. Wherever it actually sweeps close along a coast, it may bear away some detritus, to drop it over the bottom in the neighboring waters. The flow of the Gulf Stream against the submerged slope of the oceanic basin (at the rate of a mile or more per hour) is sufficient to keep the bottom free from loose detritus. Verrill has suggested that the burrowing of fishes for food aids the erosive action of currents, by loosening the material.

The oceanic currents flowing from polar seas produce important effects by means of the icebergs which they bear into warmer latitudes. These icebergs are sometimes freighted with earth and rocks; and, wherever they melt, they drop all to the ocean's bottom. The sea about the Newfoundland banks is one of the regions of melting icebergs; and there is no doubt that vast submarine accumulations of such material have been made there by this means.

DISTRIBUTION OF MATERIAL, AND FORMATION OF MARINE AND FLUVIO-MARINE DEPOSITS.

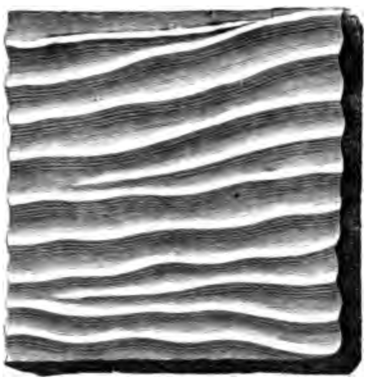
Origin of Material. — The material used by the waves and currents is either — (1) the stones, gravel, sand, clay, or earth produced by the wear of coasts; or (2) the detri-

Where the stream is small, the ocean may throw a sand-bank quite across its mouth, so that there may be no egress to the river waters except by percolation through the sand; or, if a channel is left open, it may be only a shallow one.

STRUCTURE OF THE FORMATIONS.

Beach Formations are very irregular in stratification in their upper portions, where they are made by the toss of the waves combined with drifting by the winds. The layers — as shown in Fig. 184 — have but little lateral extent, and change in character every few feet. But the sloping part swept by the waves below high-tide level is very evenly stratified parallel to the surface; and, since this surface dips usually at an angle of 5° to 15°, the beach-made beds have the same dip. The coarsest beaches have the steepest slopes.

Fig. 185.



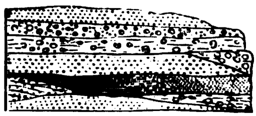
Ripple-marks.

The sand banks and reefs made in shallow waters along a coast have a more regular and more nearly horizontal stratification, and are mostly composed of sand with some beds of pebbles. They often vary much every mile or every few miles. The extent and regularity of level of the submerged area off a coast will determine in a great degree the extent to which the uniformity of stratification may extend; and, in this respect, the conditions were much more favorable for the deposit of uniformly stratified sediments over wide areas in former geological ages than at present, since large areas of the continents were formerly submerged at shallow depths.

bottom outside. They consist usually of coarse or fine sand and earthy detritus, but may include pebbles or stones when the currents are strong. The material constituting them is derived from the land through the wearing and transporting action either of the waves and currents or of rivers. The accumulations may increase under wave action in shallow water, until they approach or rise above low-tide level, and then they form sand banks. Such sand banks keep their place in the face of the waves, for the same reason as the platform of rock mentioned on page 148 and illustrated in Fig. 183.

3. *Fluvio-marine Formations.* — Most of the accumulations in progress on existing shores, whether sand banks, or estuarine, or off-shore deposits, especially about well-watered continents, contain more or less of river detritus, and are modified in their forms by the action of river currents. Along the whole eastern coast of the United States south of New England, and on all the borders of the Gulf of Mexico, the formations in progress are mainly fluvio-marine — that is, the combined result of rivers and the ocean. The coast region of the continent is now slowly widening through this means, and has been widening for an indefinite period. This coast region is low, flat, often marshy, full of channels or sounds; and facing the ocean there is a barrier of sand.

Fig. 184.



Beach structure.

The rivers pour out their detritus especially during their floods, and the ocean's waves and currents meet it as the tide sets in, with a counter action, or one from the sea landward; between the two, the waters, as they lose their velocity, drop the detritus over the bottom. Where the river is very large and the tides feeble, the banks and reefs extend far out to sea. The Mississippi thus stretches its many-branched mouth (Fig. 180) fifty miles into the Gulf. Where the tide is strong, sand bars are formed; and the stronger the tides, the closer are the sand bars to the coast.

Where the stream is small, the ocean may throw bank quite across its mouth, so that there may be n to the river waters except by percolation through tl or, if a channel is left open, it may be only a shall

STRUCTURE OF THE FORMATIONS.

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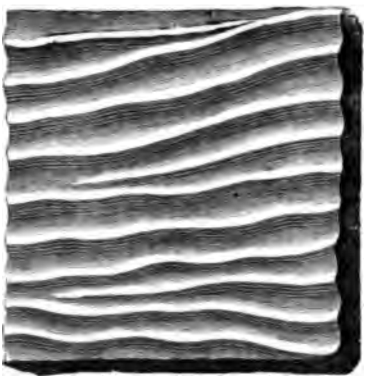
Fig. 185.



Ripple-marks.

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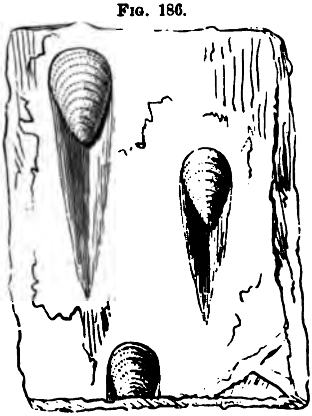
Ripple-marks (Fig. 185) are alternate ridges and furrows made by the wash of the waters over a sand flat or beach, or over the bottom within soundings. They may also be made by the action of wind on fields of sand. The width of the furrows may be a fraction of an inch, or several inches. *Rill-marks* (Fig. 186) are produced when the return waters of a tide, or of a wave that has broken on a beach, flow by an obstacle, as a shell or pebble, and are piled up a little by it, so as to be made to plunge over it, and so erode the sands for a short distance below the obstacle. The figure shows such markings in connection with shells (*Lingula*) in a Silurian sandstone.

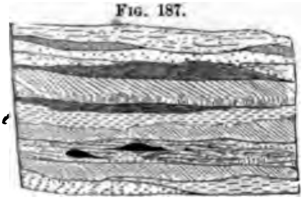
Fig. 186.



Rill-marks.

The *cross-bedded* structure (Fig. 187) is characterized by lamination or straticulation in a plane oblique to that of the stratification. It results from the pushing along of the sand or earth by currents, causing at first a little elevation, and then the deposition of successive layers over the front, or down-stream, slope of the elevation. If the currents are transient, alternating with conditions of still water, the obliquely laminated beds will alternate with others horizontally laminated. Such alternations may be due to changes of tide, or to the periodical or occasional fluctuations in the volume of rivers. When there are plunging waves accompanying the rapid flow of a current, the obliquely laminated layer is broken up into short, wavelike parts,—as in the *flow-and-plunge* structure (Fig. 188).

Fig. 187.



Cross-bedded structure.

Mud-cracks, Earth-cracks. — When a mud flat is e posed to the air or sun to dry, as by the ebbing of a ti or the subsiding of a freshet, it becomes cracked to a fe inches or feet in depth. Fig. 189 represents mud-crac in argillaceous sandstone. Such cracks may subsequent

FIG. 188.

Flow-and-plunge structure.

become filled with stony material, either sediment material in solution; and, as such fillings are often hard than the rock itself, they may stand as prominent ridg above a weathered surface of the rock. It is actually

FIG. 189.

Mud-cracks.

network of veins, but of very shallow veins that we filled from above. In regions of long droughts, the eart cracks over prairies and alluvial flats are sometimes ma and deep, and over a foot wide.

The imbedded shells and other animal relics in a bea are commonly broken; those in the bays or offsho waters out of the reach of the waves may be unbroken, or may lie as they did when living; but, if the waters are so shallow that the shells or corals are exposed to wave action, they may be broken or worn to powder, and enter in this state into the formation in progress. (See pages 99–105 for further discussion of the formation of limestone from shells or corals.)

Deposits of broken shells under water are sometimes made by Fishes that have taken the animals for food. Such beds made by Fishes answer to the shell heaps of human origin.

In the sands of beaches near low-tide level, borings of Worms, Mollusks, or Crustaceans, may exist; and, if sand or mud is left above the water level, as by the receding tide, it may be marked by tracks of various land animals.

3. Freezing and Frozen Waters.

Freezing Water. — As water in the act of freezing expands after reaching 39.2° F. (4° C.), freezing in the seams of rock opens the seams and tears masses asunder. The expansion on reaching 32° F. is $\frac{1}{35}$ lineally, and the density is diminished to 0.92. The results of expansion are most marked in rocks that are much fissured, or intersected by joints, or that have a slaty or laminated structure. As the action continues through successive years and centuries, it often results in great accumulations of broken stone. The slope, or talus, of fragments at the foot of a cliff of trap or basalt is often more than half as high as the cliff itself. In tropical countries, cliffs have no such masses of ruins at their base.

Granular rocks, whether crystalline or not, when they readily absorb water, lose their surface grains by the same freezing process. Granite, as well as porous sandstones, may thus be imperceptibly turning to dust, earth, or gravel. In Alpine regions this action may be incessant.

Alternate freezing and thawing produces (as explained rowings and widenings, its irregular bottom; and the stiff ice, compelled to accommodate itself to these irregularities, forms by its rupture profound crevasses, besides multitudes of cracks that are not visible at the surface. There are crevasses on the convex side of every bend in the glacier; transverse crevasses, crossing even its whole breadth, where the ice plunges down a steep place in an ice cascade; and longitudinal crevasses, where the ice, escaping from a narrow gorge, spreads laterally over a broad valley or plain. Independently of any local irregularities, the more rapid motion of the central part of a glacier causes a diagonal strain (theoretically in a direction at an angle of 45° with the axis of the glacier), which produces a series of marginal crevasses, having the direction indicated by Fig. 190.

Fig. 190.

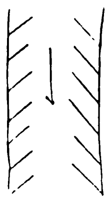


Diagram illustrating marginal crevasses.

Again, crevasses once formed may close up again, when the form of the valley is such that a portion of the ice is subjected to pressure in a direction in which it has formerly been subjected to tension.

Glacier Torrent. — The melting of the glacier, especially during the warm season, gives rise to streams of water flowing beneath it, which finally unite in a torrent of considerable size, emerging to the light from beneath the bluff of ice in which the glacier terminates. Thence it continues on its rocky course down the valley.

Method of Movement. — The capability of motion in a glacier is dependent (1) partly on a degree of plasticity in ice. Ice may be made, through pressure, to copy a seal, or may be drawn out into cylinders; or, if a slab is supported only at the sides, it will become bent downward, through gravity. The apparent plasticity of glacier ice is, however, in great part due to the processes referred to in the next two paragraphs.

(2) The movement depends in great part upon the facil-

in 14½ years. The rate in winter is about half of that in summer.

As with rivers, the central portions move most rapidly, the sides and bottom being retarded by friction.

The snow of the mountain tops, called *névé*, or *firn*, which is perhaps hundreds of feet deep, becomes compacted and converted into ice mainly by its own weight, with the aid of water penetrating it, derived from partial melting; and thus the glacier begins. Through alternate melting and freezing, the change to ice is made more complete. As the glacier starts on its course, the clouds furnish new snows to keep up the supply and help press on the moving mass.

Descent below the Snow Line. — The height, in the Alps, of the snow-line, or that below which the snow annually precipitated melts during the year, is about 8400 feet on the north side of the Alps, and about 8800 feet on the south side; and the glacier may descend below this line 5000 feet or more. The ice resists the melting heat of summer because of its mass, like the ice in an ice-house. Though starting where all is white and barren, it passes by regions of Alpine flowers, and often continues down to a country of gardens and human dwellings before its course is ended. Thus, the *Glacier des Bois*, an upper portion of which is called the *Mer de Glace*, rises in Mont Blanc and other neighboring peaks, and terminates, like several other glaciers, in the vale of Chamouni. In a similar manner, two great glaciers descend from the heights of the Bernese Alps to the Grindelwald valley just south of Interlaken.

Fig. 191 represents one of the ice streams of the Monte Rosa region in the Alps, from a view in Professor Agassiz's work on Glaciers. It shows the lofty regions of perpetual snow in the distance; the bare rocky slopes that border it, later on its course; and the many crevasses that intersect the surface of the ice stream.

Fractures attending the Movement; Crevasses. — Every valley has its ridgy sides, its sharp turns, its abrupt narthe crystals of the snowflakes on the mountain summits to a diameter of several inches near the end of a glacier; and this indicates a great amount of melting and freezing. This process goes on most rapidly when the greatest amount of heat is communicated to the glacier. Hence the motion is more rapid in summer than in winter.

(4) A glacier may, here and there, at times, slide along its bed, yet only portions at a time.

Transportation by Glaciers; Moraines. — Glaciers become laden with stones and earth falling from the heights above, or coming down in avalanches of snow and stones. The stones and earth make a band along either border of a glacier, and such a band is called a moraine. When two glaciers unite, they carry forward their bands of stones with them; but those on the uniting sides combine to make one moraine, which is called a medial moraine, in distinction from the lateral moraines on the margins of the glacier. A large glacier, like that in Fig. 191, may have many moraines — one more than the number of tributaries by whose union the trunk glacier has been formed.

In the lower part of a glacier the several moraines generally lose their distinctness, through the melting of the ice, and also by reason of the fact that the glacier is generally compressed in its lower part to a width very much less than the aggregate width of its tributaries. The surface of the glacier, accordingly, often becomes covered with earth and stones for the greater part of its breadth. The bluff of ice which forms the foot of a glacier is often a dirty mass, scarcely revealing superficially its real nature.

Some of the masses of rock on glaciers are of immense size. One is mentioned containing over 200,000 cubic feet — which is equivalent in cubic contents to a building 100 feet long, 50 feet wide, and 40 feet high.

Besides the superficial moraines, a glacier also gathers rock material from the bottom over which it moves. The disintegrated and decomposed rock is mostly scraped from the surface, masses of rock are torn off from jointed ledges, ity with which ice breaks, and afterwards reunites into a solid mass when the broken surfaces are brought into contact. This property of regelation was first noticed by Faraday. It is easily shown by breaking a lump of ice and bringing the surfaces again into contact: if moist, as they are at the ordinary temperature, they at once become firmly united. A glacier moves on and accommodates

FIG. 191.

Glacier of Zermatt, or Gorner Glacier.

itself to its uneven bed by breaking; and, however fractured it may be, it becomes, when the parts are pressed together, as solid as before.

(3) The movement of the ice is facilitated by alternate melting and freezing in the interior of the glacier. The crystalline grains of which the glacier is composed, are found to increase from the almost microscopic size of

the crystals of the snowflakes on the mountain summits to a diameter of several inches near the end of a glacier; and this indicates a great amount of melting and freezing. This process goes on most rapidly when the greatest amount of heat is communicated to the glacier. Hence the motion is more rapid in summer than in winter.

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3. ICEBERGS.

When glaciers, like those of Greenland, terminate in the sea, the icy foot becomes broken off from time to time; and these fragments of glaciers, floated away by the sea, are icebergs. The geological effects of icebergs have been stated on page 151. Seashore ice sometimes carries stones and gravel far out to sea.

Summary. Formation of Sedimentary Strata.

The following is a brief recapitulation of the explanations of the origin of deposits given in the preceding pages. Igneous and other crystalline rocks are not here included.

1. **Sources of Material.** — The greater part of the material of sedimentary rocks has come from the degradation of preëxisting rocks. But another part (as limestone and infusorial earth) has been taken up from a state of solution in the ocean or in fresh waters, through the agency of life; yet the waters have received the ingredients from the rocks, either when the ocean first began to exist, or subsequently through the dissolving action of streams on exposed rocks (page 137).

2. **Means of Degradation.** — The principal means of degradation are the following: — (1) Erosion by moving waters, either those of the sea or land (pages 126, 147); (2) Erosion by ice, chiefly in the condition of glaciers (page 163); (3) Pressure of the water descending into fissures; (4) Formation of substances, for example oxide of iron, in cracks, tending to open and deepen the cracks; (5) Growth of rootlets, roots, and trunks of trees, in crevices, resulting in opening and tearing apart rocks, and often producing extensive destruction of rocks, especially when they are jointed; (6) Freezing of water in fissures (page 157); (7) Chemical decomposition of one or more of the ingredients of a rock, in the course of which process the rock

becomes crumbled or reduced to earth; (8) Removal by solution, as of limestones by carbonated waters; (9) Undermining of rocks by any method; (10) Expansion and contraction by heat (page 172).

3. **Formation of Deposits.** — The principal methods by which deposits have been formed are the following: —

1. *By the Waters of the Sea.* — (1) Through the sweep of the ocean over the submerged portions of the continents (pages 12, 154): — making sandy or pebbly deposits near or at the surface where the waves strike, or at very shallow depths where swept by a strong current; argillaceous or shaly deposits near or at the surface, where sheltered from the waves, and also at considerable depths, out of material washed off the land by the waves or currents; but not making coarse sandy or pebbly deposits over the deep bed of the ocean, as even great rivers carry only silt to the ocean; and not making even argillaceous deposits over the ocean's bed except along the borders of the land, unless by the aid of a very great river like the Amazon, though even in that case the greater part of the detritus is thrown back on the coast by the waves and currents. In former geological periods, the submerged borders of the continents, on which sedimentation mainly takes place, were much more extensive than at present.

(2) Through living species, and mainly Mollusks, Molluscoids, Crinoids, Corals, and Rhizopods, affording calcareous material for strata; and Diatoms, Radiolarians, and Sponges, affording siliceous material. Most rocks made of Corals and the shells of Mollusks have required the help of the waves, at least to fill up the interstices.

2. *By the Waters of Lakes.* — Lacustrine deposits are essentially like those of the ocean in mode of origin, unless the lakes are small, when they are like those of rivers.

3. *By the Running Waters of the Land.* — (1) Filling the valleys with alluvial deposits, and moving the earth from the hills over the plains (page 138). (2) Carrying detritus to the sea or to lakes, to make, in conjunction

with the action of the waters of sea or lake, deltas and other shore accumulations (pages 138, 153).

4. *By Frozen Waters.* — (1) Acting in the condition of glaciers; and thus spreading the rocks and earth of the higher lands over the lower, in definite lines of moraine, or in sheets of drift, bearing onward in the process, blocks of great size, as well as finer material (page 162). (2) Acting as icebergs; and, in this condition, transporting stones and earth to distant parts of the ocean, as from the Arctic regions to the Newfoundland Banks, and so contributing to sedimentary accumulations in deep or shallow water, distinguished by their containing huge blocks of stone, besides pebbles and earth.

V. HEAT.

1. Sources of Heat.

The crust of the earth derives heat from three sources: — 1, *The Sun*, an external source; 2, *The Earth's Heated Interior*; 3, *Chemical and Mechanical Action.*

1. **The Sun.** — This agency is peculiar in being regularly variable, through the alternations in day and night, in the seasons, in the time of aphelion and perihelion, and in the eccentricity of the earth's orbit. The amount of heat imparted to the earth and retained by it, varies also with changes in the atmosphere; since the atmosphere absorbs a part of the heat radiated to the earth from the sun and stars, and absorbs in greater proportion the heat rays of extremely great wave length radiated from the earth. The following are some of the causes to which change in climate has been attributed: —

1. A gradual diminution in the heat of the sun through the geological ages. Such a change must have taken place; and it is believed by Lord Kelvin and others that it has been adequate to produce a very considerable change in the earth's climate since the beginning of Paleozoic time.

2. Variations in the condition of the surface of the sun, causing periodical alterations in the amount of heat radiated, and thus producing alternating cold and warm eras. Such changes are possible, though their occurrence has not been proved.

3. Variations in the level of the earth's surface. In any latitude the highlands are colder than the lowlands, so that very appreciable changes of climate must have been produced by the great mountain elevations of the Tertiary era, and by the extensive changes of continental levels in the Quaternary. But even more important may be the indirect effects of crustal movements, when a change in the level of the land or sea bottom diverts the oceanic currents from one course to another. Elevating the sea bottom between Europe and Greenland, would shut out the warm Gulf Stream from the Arctic region, and increase its cold. For, according to Croll's calculations, this stream contributes to the North Atlantic Ocean 77,479,650,000,000,000,000 foot-pounds of energy, in the form of heat, per day. Such a change might, therefore, make a glacial climate for large areas in the northern hemisphere. On the contrary, a subsidence opening Bering Strait for the free passage of the tropical current of the Pacific would ameliorate the Arctic climate.

4. Variations in the constitution of the earth's atmosphere. As already stated, the atmosphere absorbs a part of the heat radiated from the sun to the earth, but absorbs in greater proportion the heat rays of very great wave length emitted from the earth. The effect of the atmosphere is to make the temperature of the surface of the earth more uniform, and on the average higher, than it would otherwise be. This absorptive action is chiefly due to the carbon dioxide and water vapor in the atmosphere. It has been inferred that the effect of a larger amount of these constituents (which must have existed in early geological time) would have been to make the earth warmer than at present. The researches of Langley,

with the action of the waters of sea or lake, deltas and other shore accumulations (pages 138, 153).

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eccentricity, since the effect of precession and revolution of the apsides is to reverse the relation of the seasons of each hemisphere to aphelion and perihelion twice in a cycle of about 21,000 years. In an age of maximum eccentricity, Glacial epochs should accordingly occur alternately in the northern and the southern hemisphere, culminating at intervals of 10,500 years.

6. A change in the earth's axis has been suggested as a possible cause of variation in climate. But calculations by G. H. Darwin, Haughton, and others, have shown that no such change can have taken place sufficient for any marked result.

2. **Internal Heat.** — The fact of a high temperature in the earth's interior is established in various ways.

1. The form of the earth is a spheroid, and a spheroid of just the shape that would have resulted from the earth's revolution on its axis, provided it had passed through a state of fusion, and had slowly cooled over its exterior. Hence is drawn the inference that it has passed through such a state of fusion, which is strengthened by the other evidence here given. Another conclusion also follows; namely, that the earth's axis had the same position (or, at least, very nearly the same) when cooling began as now. There is no evidence that there has been at any time any considerable change.

2. In deep borings for water, and in shafts sunk in mining, it has been found that the temperature of the earth's crust increases, on an average, one degree Fahrenheit for 55 to 60 feet of descent. Such a rate, in the latitude of New York, would give heat enough to boil water at a depth of less than two miles; and at a depth of 35 miles the temperature would be 3000° F., or that of the fusing point of iron. Since, however, the fusing temperature of nearly all substances increases with the pressure, a zone of universal fusion in the earth, if such a zone exists at all, must be at a much greater depth than would be suggested by the figures given above.

however, have shown that the law of selective absorption of heat rays by the atmosphere is more complex than was formerly supposed; and the inference as to the climatic effect of the greater amount of water vapor and carbon dioxide in former times, is somewhat doubtful.

5. Variations in the eccentricity of the earth's orbit. The earth, through all such variations, receives the same amount of heat annually from the sun, but not the same for the winter as for the summer. The maxima of eccentricity are unequal, and are passed at variable periods ranging from about 100,000 to somewhat more than 200,000 years. The earth is at present near a minimum, and the distance from the sun is about 93.9 millions of miles in aphelion (which comes now in summer), and nearly 90.9 millions in perihelion — the difference, about 3 millions. About 100,000 years since, a maximum occurred, with the aphelion and perihelion distances 96.65 and 88.15 millions of miles — the difference, $8\frac{1}{2}$ millions; and 850,000 years since, an extreme maximum, with these distances 99.3 and 85.5 millions — the difference, 13.8 millions of miles. When the aphelion comes in the winter of the northern hemisphere, the cold of the winters in that hemisphere is increased, the amount of heat received being inversely as the square of the distance (which ratio gives for the heat in winter, during the extreme maximum referred to, about five sixths of that now received in that season). Moreover, the winter part of the year (from the autumnal to the vernal equinox) is, at the extreme maximum, 36 days longer than the summer part (from the vernal to the autumnal equinox); whereas at present the latter is 8 days the longer. At the same time, the summers are hotter, but shorter. In the southern hemisphere the reverse, in each respect, is true. The cold of a Glacial period has been thus accounted for, and also the warmth of warm eras, by Croll; but others reject the theory. The theory requires several Glacial epochs in each hemisphere during one prolonged time of maximum

become liquid or solid, or when liquids (as water) become solid. It is also produced in many chemical changes, as in the oxidation of pyrite and other substances.

2. Effects of Heat.

The following are the effects of heat here considered: — 1, *Expansion and Contraction*; 2, *Eruptions of Igneous Rock, and associated phenomena*; 3, *Metamorphism*; 4, *Formation of Veins*.

The subject of movements of the earth's crust, and the evolution of continents and mountain ranges, might be included here, since these movements probably result from the reaction of the earth's heated interior upon its surface; but the subject is so comprehensive that it has been deemed best to give it a distinct chapter (page 203).

1. EXPANSION AND CONTRACTION.

(1) Heat from any subterranean source penetrating upward may cause wide changes of level. Lyell has calculated that a mass of sandstone a mile thick, raised in temperature to 1000° F., would have its upper surface elevated 50 feet. Fractures and displacements would be likely to attend such movements. (2) The diurnal variation of temperature, which in some countries amounts to 80° F. or more, and also the annual variation, is a force always at work. The expansion and contraction may gradually move blocks of rock from their places. It will move the heated side of the block outward; and, if this outer part so moved cannot, because of wedging or friction, return with the succeeding contraction, the mass will move to it or have its edges fractured. Blocks lying on a slope will tend to crawl downward, since gravitation will make the downward movement slightly exceed the upward, in both expansion and contraction. The Bunker Hill obelisk at Charlestown in Massachusetts has been proved to swing back and forth with the passage of the sun over it. (3) The alternating action of expansion and

3. The great Pacific Ocean has nearly a complete girdle of volcanoes, extinct or active; and all of its many islands that are not coral islands, are volcanic, excepting New Zealand and a few others of large size in its southwest part. Volcanoes occur along many parts of the Andes from Tierra del Fuego to the Isthmus of Darien; in Central America, in Mexico, California, Oregon, and beyond; in the Aleutian Islands on the north; in Kamchatka, Japan, the Philippines, New Guinea, New Hebrides, and New Zealand on the west; and in Antarctic lands south of New Zealand and South America. The volcanic region thus bounded is almost a hemisphere; and, besides, there are volcanoes in many parts of the other hemisphere. Outlets of molten matter so extensively distributed seem to indicate that there is some world-wide region of heat beneath.

4. The flexures which the earth's crust and its strata have undergone over regions of continental extent, and even as late as the Cenozoic, have been held by some to prove that there have been, up to the middle Cenozoic, if not later, great regions of liquid rock beneath the earth's crust; though most physicists and geologists believe those movements to be compatible with a condition of substantial solidity of the globe.

3. **Chemical and Mechanical Action.** — In the upturning and flexure of rocks attending mountain-making, there have been movements on a grand scale; and, through the transformation of this motion into heat, the rocks have received in some cases a high temperature, sufficient to promote, through the moisture present, the consolidation of rocks, and even their crystallization, or metamorphism; and also, in the view of Mallet, their fusion on a scale grand enough to originate volcanoes. This is probably one chief source of the heat through which the metamorphism and consolidation of rocks have been produced, the other chief source being the internal heat.

Heat is produced by condensation, as when vapors wide regions wherever metamorphism is in progress; and the subsequent cooling and contraction may leave multitudes of fractures, in long lines or in reticulations, the subsequent filling of which may make veins.

Drying is another source of shrinkage cracks. It makes the shallow mud-cracks (page 156), and the soil-cracks, sometimes yards in depth, in countries of fertile prairies that have a long hot and dry season; and may produce far deeper jointlike cracks in mud-made rocks (shales and argillaceous sandstones), as they become slowly dried by the action of subterranean heat. Further, the drying of beds produces a sinking of the surface. A soft mud may contract to a tenth of its bulk. All mud beds will suffer a large diminution in thickness on drying; but the pressure of overlying strata may prevent shrinkage cracks from forming.

2. ERUPTIONS OF IGNEOUS ROCK, AND ASSOCIATED PHENOMENA.

General Nature of Volcanoes and their Products.

Volcanoes are mountain elevations of a somewhat conical form, which have a crater at the summit, and eject, from time to time, vapors and melted rock. If the ejections have long since ceased, the volcano is said to be extinct.

The cavity or pit in the top of a volcanic mountain, called the crater, where the lavas may often be seen in fusion, is sometimes thousands of feet deep, but may be quite shallow; and in extinct volcanoes it is often wholly wanting, owing to its having been left filled when the action ceased.

The liquid rock issuing from a crater, and the same after becoming cold and solid, is called lava.

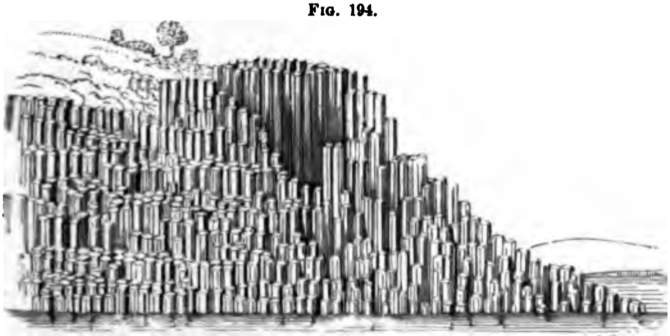
An active crater, even in its most quiet state, emits vapors. These vapors are mostly steam, or aqueous vapor; but in addition there are usually sulphur gases, and some-contraction peels off the grains or outer surface of rocks, and is, especially in dry climates, an important means of rock disintegration.

Shrinkage Cracks. — (1) In the cooling of liquid rocks shrinkage cracks are produced, and thence comes the columnar structure of trap, basalt, etc. (Fig. 193). The columns show a tendency to the form of hexagonal prisms, since less expenditure of force in the rupture of cohesion is required to produce a hexagonal network of cracks than one of any other form. The cracks tend to be propagated in a direction perpendicular to the cooling surface; and the position of the columns is thereby determined. Fingal's Cave

FIG. 193.

Columnar structure.

FIG. 194.



Basaltic columns, Illawarra, New South Wales.

and the Giant's Causeway are familiar examples of columnar structure in great perfection. Fig. 194 (from a sketch by the author in 1840) illustrates the same phenomenon at Illawarra on the coast of New South Wales. (2) Similar columnar forms are sometimes produced in sandstone after heating, though in general only irregular cracks result. (3) Heat penetrates rocks over wide regions wherever metamorphism is in progress; and the subsequent cooling and contraction may leave multitudes of fractures, in long lines or in reticulations, the subsequent filling of which may make veins.

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An active crater, even in its most quiet state, emits vapors. These vapors are mostly steam, or aqueous vapor; but in addition there are usually sulphur gases, and some times carbonic acid, hydrochloric acid, and more rarely other gases.

In a time of special activity fiery jets are sometimes thrown up to a great height, which are made of red-hot fragments — the fragments of great bubbles of lava produced by the escaping vapors. The fragments cool as they descend about the sides of the crater, and are then called cinders or ashes, according as they are coarse or fine.

When a shower of rain (which often results from the condensation of the escaping steam) accompanies the fall of the ashes, the result is a mudlike mass, which becomes, on drying, a brownish or yellowish brown rock called tufa. Tufa is often much like a soft sandstone, except that the materials are of volcanic origin.

The materials produced by the volcano are, then: — 1, *Lavas;* 2, *Cinders* and *ashes;* 3, *Tufas;* 4, *Vapors* or *gases.*

The lavas are of various kinds. They are often more or less cellular — sometimes light cellular, like the scoria of a furnace, — but more commonly heavy rocks, with some scattered ragged cellules or cavities through the mass. A stream of lava of this more solid kind has often a few inches of scoria at top, as a running stream of sirup may have its scum or froth. The most of the scoria has this scum-like origin. Pumice is a very light grayish scoria, full of long and slender parallel air cells.

When lava cools rapidly, it solidifies as a glass — obsidian or tachylite (pages 38, 39). When it cools slowly, it forms a truly crystalline rock. Between the extremes are various gradations.

The stony, or crystalline, lavas may be divided into three groups, according to their chemical and mineralogical constitution, of which basalt, andesite, and trachyte may be considered types. The lavas of the first group consist chiefly of pyroxene and labradorite. They contain a relatively small amount of silica, are dark and heavy rocks (specific gravity above 2.8), and have an average

General Description of Hawaii. — Hawaii is made up mainly of three volcanic mountains — two, Mauna Kea and Mauna Loa (Figs. 196, 197, page 177), nearly 14,000 feet high; and one (the western), Mauna Hualalai, about 10,000 feet. Mauna Kea is alone in being extinct.

Mauna Loa has a great crater at its summit, and another independent one 4000 feet above the level of the sea. The latter is the famous Kilauea, called also *Lua Pélé*, or Pélé's pit, Pélé being, in the mythology of the Hawaiians, the goddess of the volcano.

The accompanying map of Hawaii (Fig. 198) shows the positions of Mauna Loa and Mauna Kea, and of the crater of Kilauea.

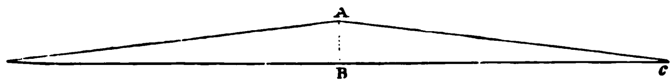
Kilauea. — The crater of Kilauea is literally a pit. It is three miles in greatest length, and nearly two in greatest breadth, and about seven and a half miles in circuit. The pit has nearly vertical sides of solid rock (made of lavas piled up in successive layers), and has been 1000 feet in depth after several of its eruptions, and 400 to 600 feet previous to its eruptions. The bottom is a great area of solid lava, with one or more lakes or pools of liquid lava, or crater-like openings, from which vapors rise. The largest lake, in 1840, was 1000 feet in diameter. The interior may be surveyed from the brink of the pit, even when in most violent action, as calmly and safely as if the landscape were one of houses and gardens.

Action in Kilauea. — The ordinary action, in the intervals between the great eruptions, is simply this. The lavas in the active pools are in a state of ebullition, jets rising and falling as in a pot of boiling water — with this difference, that the jets are 30 to 100 feet high. Such jets, in lava as well as water, arise from the effort of vapors to escape; in water the vapor is steam derived from the water itself; in lavas it is chiefly steam from waters that have gained access to the lavas, but also gases and vapors derived from materials in the lavas, or from depths below.

The lavas of the pools or lakes overflow at times and

The cone of Vesuvius, shown in Fig. 195, consists mostly of cinders, and is accordingly pretty steep. Etna, about 10,000 feet high, and Mauna Loa in Hawaii, nearly 14,000 feet, consisting mainly of lava streams, have an average slope of less than 10°. The form of a cone with a slope of 7° — which is the average for the Hawaiian volcanoes — is shown in Figs. 196, 197. Fig. 196 has a pointed top like Mauna Kea, and Fig. 197 a rounded out-

FIG. 196.

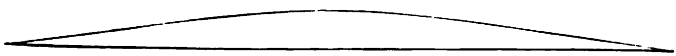


Mauna Kea.

line like Mauna Loa, whose form is that of a very low dome.

The highest of volcanic mountains on the globe are the Aconcagua peak in Chile, 23,000 feet, and Sorata and Illimani in Bolivia, each over 24,000 feet. The former appears to be still emitting vapors. The mountains

FIG. 197.



Mauna Loa.

Shasta, Hood, St. Helen's, and others in California and Oregon, are isolated volcanic cones 11,000 to 14,400 feet high, the latter being the height of Mount Shasta. The average slope of the upper half of Mount Shasta is about 27°. The slopes of most of the lofty volcanoes of the Andes are between 25° and 34°.

Volcanic Eruptions.

The process of eruption, though the same in general method in all volcanoes, varies much in its phenomena. The fundamental principles are well shown at the great craters of Hawaii, the southeasternmost of the Hawaiian (or Sandwich) Islands.

1823 and 1832, and between 1832 and 1840, the bottom was raised 400 feet or more above the lowest level, so that the depth was reduced from 1000 feet to 600 feet or less. The addition of 400 feet to the height of the column of liquid lava in the crater caused a corresponding increase of pressure against the sides of the mountain. The amount of this pressure is at least two and a half times as great as that which a column of water of equal height would produce. The mountain must be strong to bear it. The lavas at such times may be in a state of violent activity, and a large addition to the pressure against the sides of the mountain comes from the force of the imprisoned vapors.

The consequence of this increase of pressure, both from the lavas and the vapors, may be, and has several times been, a breaking of the sides of the mountain. One or more fractures result, and out flows the lava through the openings. Thus simple have been the eruptions.

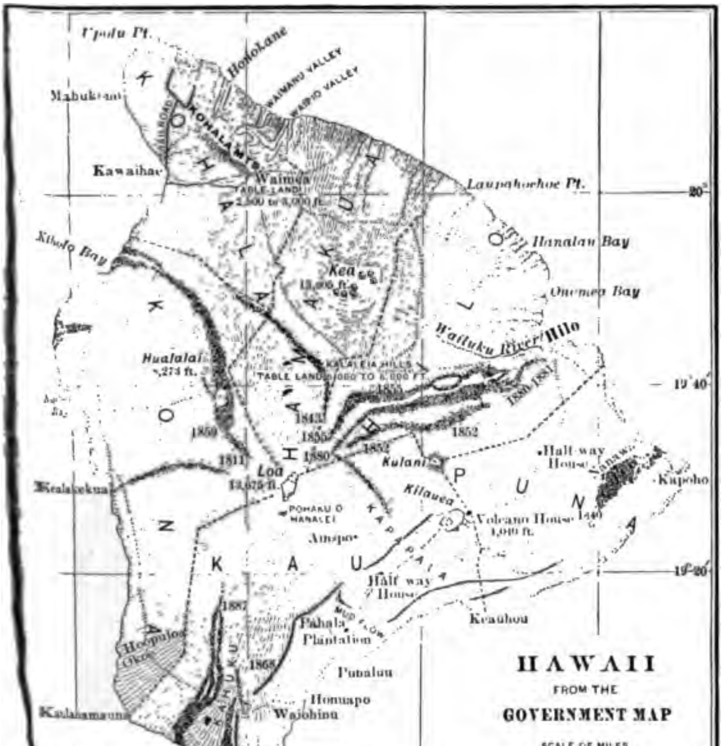
In the eruption of 1840 the lavas first appeared at the surface a few miles below Kilauea, and then again at other points somewhat more remote; finally a stream (represented on the map, Fig. 198) began at a point about 15 miles east of the great crater, and extended to the shores at Nanawale. Here, on encountering the waters, the great flood of lava was shivered into fragments, and the whole heavens were thick with an illuminated cloud of vapors and cinders, the light coming from the fiery stream below. The lavas which escaped at this relatively small eruption amounted to at least 15,400,000,000 cubic feet.

This eruption of Kilauea took place, it will be observed, not over the sides of the crater, but through breaks in the mountain's sides below; and the pressure of the column of lava within, and that of the escaping vapors, appear to have caused the break.

Summit Crater of Mauna Loa. — Eruptions have also taken place from the summit crater of the same mountain (Mauna Loa), which is nearly 14,000 feet above the sea;

... in streams across the great plain that forms the bottom of the crater. In times of great activity the pools and lakes are numerous, the ebullition incessant, the jets

FIG. 198.



higher, and the overflowings follow one another in quick succession.

Cause of Eruption. — In part as the result of these overflows, but in part (and sometimes chiefly) as the result of the bodily uplifting of the crater floor by lavas ascending beneath it, the pit slowly fills. In the intervals between the pressure; and that finally the mountain, when it can no longer resist the forces within, somewhere breaks and lets the heavy liquid out. They show (2) that, while earthquakes may attend volcanic action, they are no necessary part of it. They show (3) that lavas may be so very liquid that no cinders are formed during a great eruption; for, in the ebullition of the lava in the boiling lakes of Kilauea, the jets (made by the confined vapors) are usually thrown only to a height of 30 to 100 feet; and, on falling back, the material is still hot; it either falls back into the pool or lake, or becomes plastered to its sides. The liquidity of the lavas is shown by the jetting out sometimes, from small holes, of drops but a fourth of an inch thick, which fall back on one another, adhere, and so make a model of a fountain.

Vesuvius. — Vesuvius is an example of another type of volcano. The characteristic of the Hawaiian type of volcanoes is the comparatively perfect liquidity of the lavas. The lavas are of the most fusible (basaltic) type; and the temperature is so high that they are completely fused. In the case of less fusible lavas, the temperature is generally insufficient for perfect liquefaction, sufficing only to bring them to a viscid, semifused condition. In Vesuvius, the lavas are so viscid that jets cannot rise freely over the surface: the vapors are therefore kept confined until they form a bubble of great dimensions; and, when such a bubble, or a collection of them, bursts, the fragments are sometimes thrown to a height of thousands of feet. The crater, at a time of eruption, is a scene of violent activity, and cannot be approached. Destructive earthquakes often attend the eruptions.

In many of the eruptions of Vesuvius, there has been no outflow of lava streams, the lava emitted being all projected into the air by the violence of the explosions, and falling as cinders, ashes, or tufa. This appears to have been the case in the famous eruption in the year 79, in which Pompeii and Herculaneum were overwhelmed.

and in each case there has been, not an overflow from the crater, but an outflow through breaks in the sides of the mountain. In 1852 there was first a small issue of lavas near the summit, and then another of great magnitude about 10,000 feet above the sea level. At this second outbreak the lava was thrown up in a fountain, or mass of jets, two or three hundred feet high; and thus it continued in action for several days. The forms of the fountain of liquid fire were compared by Rev. T. Coan to the clustered spires of a Gothic cathedral. Similar lava fountains have been observed also at other eruptions of the volcano.

The pressure producing the jet in the case above mentioned, so far as it was hydrostatic, was that of the column of lava between the point of outbreak and the level of the lavas in the summit crater, 3000 to 4000 feet above. The same pressure in connection with confined vapors must have caused the breaking of the mountain in which the eruption began.

Usually, no great earthquakes accompany the Hawaiian eruptions, sometimes not even slight ones, the first announcement being merely "a light on the mountain." But the eruptions of 1868 and 1887, from the summit crater of Mauna Loa, were preceded by earthquakes of considerable violence. When the summit crater is in action, Kilauea, though 10,000 feet lower on the same mountain, and even a larger pit crater, commonly shows no agitation, no signs whatever of sympathy.

At some of the eruptions of Mauna Loa the lava has continued down the mountain to a distance of 50 or 60 miles.

The shaded bands descending from near the summit, on the map (Fig. 198), show the courses of several great outflows of lava.

Conclusions. — These cases of eruption indicate (1) that the lavas go on gradually increasing the pressure in the interior by their accumulation, while augmented activity in the production of vapors still further increases chloric acid in its vapors, and of chlorides among its saline incrustations.

Trachytic Domes. — Trachytic lavas are less common in modern volcanoes than the basaltic. They have in some cases preceded basalt in the history of a volcanic cone. In some cases these trachytic lavas (which, owing to the predominance of orthoclase in their constitution, are much less fusible than the basaltic) have come up through fissures in so pasty a state that they have swelled up into steep domes and cooled in this form. Domes of this kind occur in Auvergne; also in the Black Hills of South Dakota (Newton and Jenny).

Lateral Cones of Volcanoes. — In eruptions through fissures the lavas may continue issuing for some days or weeks through the widest or most freely open part of the fissure, and consequently form at this point a cone of cinders or lava. Thus have originated innumerable cones on the slopes of Etna and other volcanic mountains.

Submarine Eruptions. — Eruptions may sometimes take place from the submarine slopes of the mountain when it is situated near the sea, as has happened with Etna and Mauna Loa; and in such cases accumulations of tufa or of solid lava may form under water about the opened vent. The numerous volcanic islands of the ocean of course commenced with submarine eruptions. Fishes and other marine animals are usually destroyed in great numbers by such submarine eruptions.

Subsidence of Volcanic Regions; Overwhelming of Cities. — Among the attendant effects of volcanoes are the sinking of regions in their vicinity that have been undermined by the outflow of the lavas; the tumbling in of the summit of a mountain; and earthquakes, or vibrations of the rocks, in consequence of fractures. Another is the burial, not only of fields and forests, but even of cities and their inhabitants, by the outflowing streams, or by the falling cinders and accumulating tufas. Pompeii and Herculaneum are two of the cities that have been

Before that catastrophe, there was a large circular crater, the northern half of whose inclosing rampart remains as the ridge of Monte Somma (*c*, Fig. 195). In the explosions of that eruption, the southern half of the old rampart disappeared.

In the minor activity of the mountain, during the intervals between the great eruptions, the same explosive character shows itself. Instead of quiet outflows from lakes of lava, as in Kilauea, there are generally explosive discharges of cinders, building up small cones. Such a cone is shown at *b* in Fig. 195.

The lavas at Vesuvius may flow directly from the top of the crater; but they generally escape partly, if not entirely, through fissures in the sides of the mountain.

Some volcanoes, as those of Java, are characterized even more strongly than Vesuvius by the predominance of the explosive type of eruption. The eruption of Krakatoa in 1883 was a remarkable example of this type. The ashes, according to Verbeek, ascended to a height of more than 150,000 feet, and are supposed to have been carried around the world, and to have caused the red sunset glows of the autumn following. Even Kilauea is known to have had one violently explosive eruption, probably about 1789.

Besides the difference in the composition of the lavas, other circumstances, as the size of the conduit, the temperature of the subterranean reservoir, etc., affect the character of the eruption. Such extremely violent explosions as that of Krakatoa are probably due to the sudden access of a large amount of water to the molten mass.

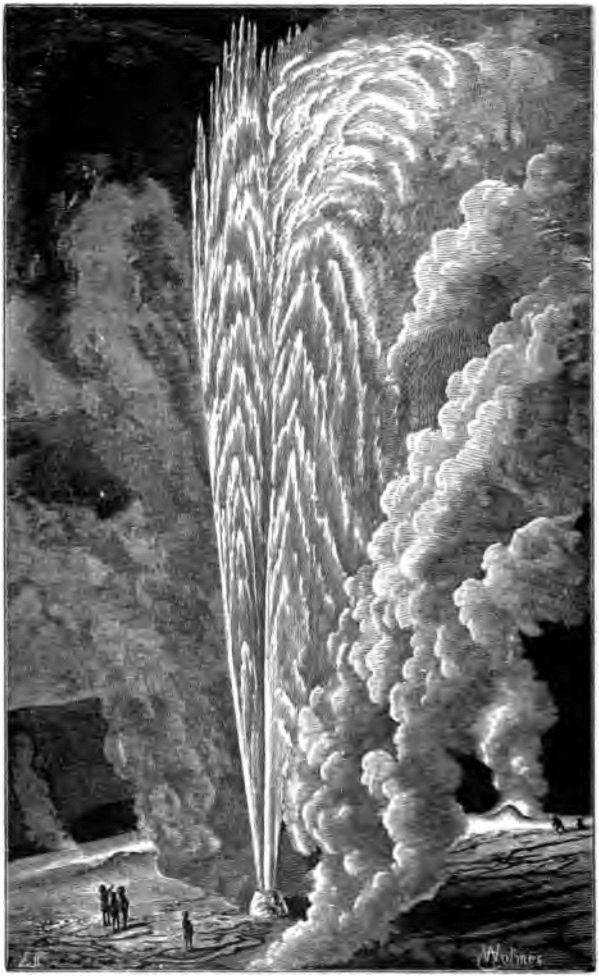
Of the two causes of eruption — hydrostatic pressure, and elastic force of confined vapors, — the latter appears to be the most effective in Vesuvius, while the former may be in Hawaii. The vapors in Mauna Loa appear to be supplied mainly by the fresh waters (rains) which fall over the mountain and descend through the rocks; while Vesuvius is, in part at least, supplied by salt waters from the Mediterranean, as is proved by the presence of hydro-

[redacted]

to several weeks. The eruptions of some are very regularly periodical, while others are very irregular.

The action of geysers is due to the condition that subterranean waters have access to hot rocks (as the interior

Fig. 199.



Beehive Geyser in action.

carried by Vesuvius; and every few years we hear of some new devastation of habitations or farms by this uneasy volcano. Pompeii is covered only by the tufas of the eruption in which it was destroyed; Herculaneum is covered also by tufas and lava streams of several later eruptions.

SUBORDINATE VOLCANIC PHENOMENA.

1. **Solfataras.** — In the vicinity of volcanoes, and sometimes in regions in which no active volcanoes exist, there are areas where steam, sulphur vapors, and perhaps carbonic acid and other gases, are constantly escaping. Such areas are called solfataras (from the Italian, *solfo*, sulphur, and *terra*, earth). The sulphur gases deposit sulphur in crystals or incrustations about the fumaroles (as the steam holes are called); and alum and gypsum often form from the action of sulphuric acid (derived from the oxidation of the sulphur gases) on the rocks.

2. **Hot Springs; Geysers.** — Fountains or springs of hot water are common in volcanic regions, and are often so abundant as to be used for baths. Such springs occur also in many other parts of the world, especially in regions of upturned or of eruptive rocks. In some cases the heat is produced by chemical changes in progress beneath, or by friction and crushing of rocks in the upheavals which have taken place; but often the source is the residual heat of great masses of lava.

When the heated waters are thrown out in intermittent jets, they are called geysers. The Yellowstone Park in the Rocky Mountains (between the parallels of 44° and 45° N., and the meridians of 110° and 111° W.) is the most remarkable region of geysers in the world, far exceeding that of Iceland. One of the geysers — the Beehive — is represented in action in Fig. 199. The Beehive jet is 200 feet high. Its eruptions occur at somewhat irregular intervals, but generally two or three times in a day. The periods of other geysers vary from less than a minute to several weeks. The eruptions of some are very reg larly periodical, while others are very irregular.

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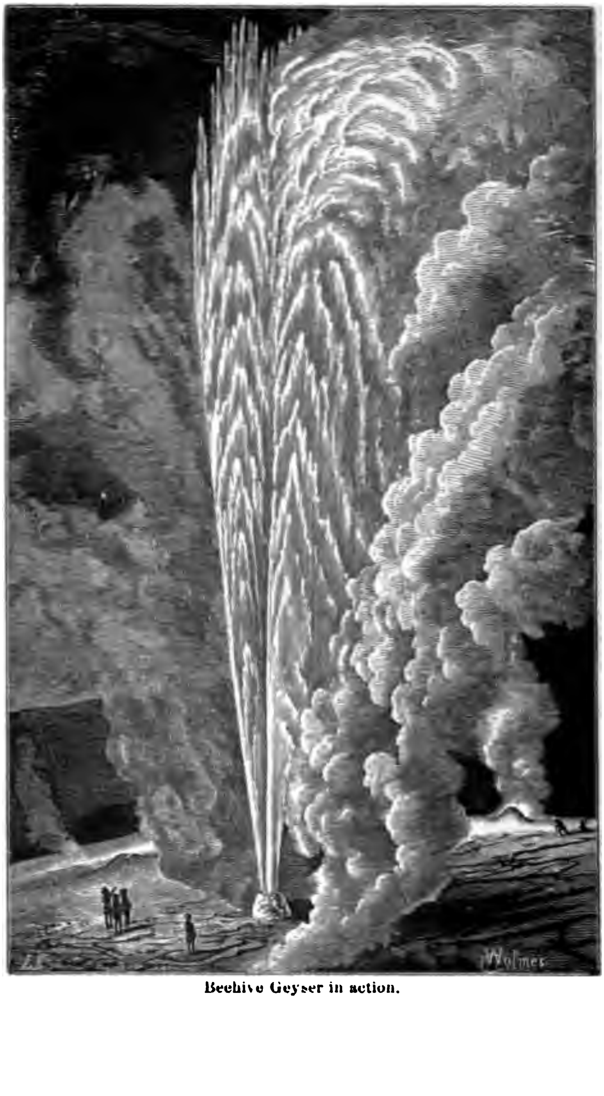

Beehive Geyser in action.

of great lava sheets, retaining a high temperature on account of the poor conductivity of the material), and that the conduit communicating with the surface is so narrow that convection currents cannot be freely established. The heat accordingly increases in the deeper part of the column of water, until steam is formed, by whose expansion the cooler waters above are explosively ejected. After an eruption, the water flows back into the underground passages, and gradually becomes heated up for another explosion.

Heated waters act on the rocks with which they are in contact, and decompose them; and, as most rocks — especially volcanic rocks — contain some kind of feldspar, the waters become slightly alkaline through the alkali of the feldspar, and so are enabled to take up silica and make siliceous solutions. The silica taken into solution is deposited again around the geyser in many beautiful forms, and makes the bowl or crater from which the waters are thrown out.

When the material in the vicinity of a boiling pool consists of earth or mud, mud cones are formed, as in some parts of the Yellowstone Park, and also at Geyser Cañon, north of San Francisco, California.

Besides hot springs that deposit silica, there are others that deposit calcium carbonate, making thus the kind of porous limestone called travertine, as on Gardiners River, Yellowstone Park.

In some cases, the action of the heated waters on the rocks exposed to them gives origin to deposits of quartz crystals, agate, opal, and different silicates and other minerals.

Igneous Eruptions Not Volcanic.

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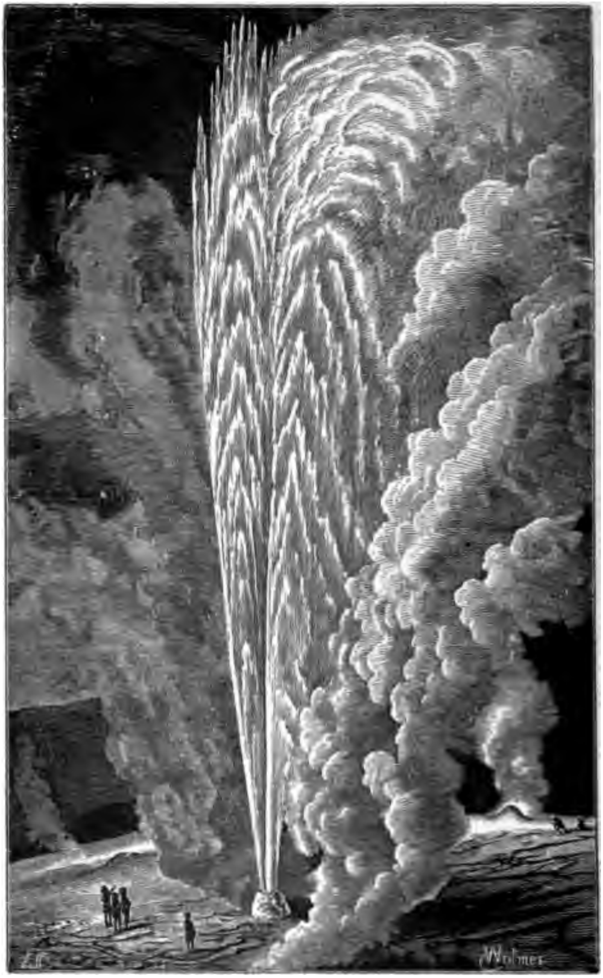

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It has been stated that eruptions of volcanoes generally take place through fissures. Fissure eruptions have occurred also in regions remote from volcanoes; and they have been the source of ejections over the western slope of the Rocky Mountains vastly greater than any from volcanic centers. The narrow mass of igneous rock that fills such fissures is called a *dike*. The liquid rock has sometimes merely filled the fissure, without overflowing; but in other cases it has spread widely over the surface, making sheets of great extent and thickness. The outflow of liquid rock has often been followed by sedimentary deposits, and then another outflow has taken place; thus making alternations of fire-made and water-made strata. In that case, the sheets of igneous rock are said to be *contemporaneous*, or *extrusive*. Beds of tufa, or "ash beds," may also be included in the series. In other cases, the strata have been parted along a plane of stratification, and molten rock has forced itself in. Such sheets are called *intrusive*. In the case of intrusive sheets, both the overlying and the underlying strata are affected by the heat of the igneous rock (local metamorphism, page 190); in the case of contemporaneous sheets, only the underlying strata.

The rocks most commonly occurring in dikes are felsite, diorite, and dolerite (pages 38, 39). The igneous rock is very often without cellules or air cavities; and, if any are present, they are in general neatly formed, instead of being ragged like those of lavas. If the cavities in such a rock are filled by the deposit of minerals (as quartz, calcite, zeolites, etc.), it is called amygdaloid. The rock of an amygdaloid is usually hydrous (and chloritic) throughout (owing, it is supposed, to subterranean waters gaining access in some way while the eruption was in progress); and the cavities were formed in the outer or upper part, where the diminished pressure allowed of the water's passing to the state of vapor.

Dikes are common on all the continents, especially in the regions between the summits of the border mountains and the ocean, which are usually between 300 and 800 miles in breadth; as, for example, between the Appalachians and the Atlantic, and between the Rocky Mountains and the Pacific.

The Pacific slope of the Rocky Mountains (500 to 800 miles wide) is remarkable for its lava floods. Some of them are around volcanoes, or volcanic vents, but many were from fissure eruptions remote from any volcano. The largest continuous area extends from the Yellowstone Park in Wyoming, westward along the Snake River through southern Idaho, and then spreads northward over most of Oregon and a large part of Washington, and southward into northern California. Its boundaries have not been exactly determined, but its area is estimated to be between 100,000 and 150,000 square miles. On the western margin are the lofty volcanoes of the Cascade Range, and a number of smaller volcanoes are dotted over various parts of the region; but it is evident that these were not the source of the widespread lavas. The Columbia River is bordered for long distances by walls 1000 to 2000 feet high, made of ranges of basaltic columns; and, in the vicinity of Mount Hood, the thickness is 3500 feet. Again, in northern California, south of the combined volcanic area of Mount Shasta and Lassens Peak, on the west slope of the Sierra, the lavas were so copious as to obliterate the deep valleys of an old system of drainage, and force the streams to make new channels. The erosion then begun has since cut out valleys 1000 to 3000 feet deep, partly along new routes, leaving the remnants of the lava field as caps of "Table Mountains." The miners have tunneled beneath the lava cap for gold-bearing gravels, and found rich deposits in the beds of the old streams (J. D. Whitney). Nevada, southern Utah, Colorado, New Mexico, and Arizona have other wide lava fields.

Still more wonderful are the fissure eruptions of the Deccan, in India, where a railway out of Bombay runs for 519 miles continuously over a lava field; its area is not less than 200,000 square miles.

In eastern North America, outflows through fissures made the Palisades on the Hudson; long narrow ranges through the Connecticut valley, including among the sumstate of steam of high pressure, it decomposes readily many of the silicates, or the ordinary minerals of rocks, and so prepares for the formation of new minerals — thus making sometimes feldspar, mica, hornblende, etc. The quartz grains of a sandstone have often been converted into minute crystals of quartz by the deposition of silica over the exterior.

The water is for the most part that contained in the rocks themselves; for beds of sandstone, limestone, etc., contain, before alteration, on an average at least 2 per cent of water (independently of any in spaces between the beds), which means 2 pints of water to 100 pounds of the rock.

The heat is (1) partly the result of mechanical action; for metamorphism has generally taken place where the rocks have undergone shoving, folding, and faulting, and sometimes crushing (see page 218): and (2) partly also, the heat of the earth's interior conducted upward into the beds (page 217); for metamorphism has generally taken place where the strata have accumulated to very great depth.

These are some of the various ways in which heat and water have operated in metamorphic changes. Direct experiments have shown that crystallization does result from the action of heat and water. Quartz crystals, feldspar, mica, and other minerals have been artificially made by the subjection of the ingredients to highly heated moisture.

Alkaline waters dissolve silica even at very moderate temperatures; and, wherever such solutions exist, they may work at consolidating, altering, and dissolving minerals, and making geodes and veins of quartz. Large corals in Florida have been hollowed out by this means, and the cavities lined with quartz crystals or agate. The fossils of a limestone have been silicified and flint nodules made even in cold waters. The ordinary decomposition of a feldspar or mica, of hornblende or pyroxene — one or more of which silicates occur as constituents of granite, syenite, trap, porphyry, trachyte, and tufa, — sets garnet, out of the ingredients present in the adjoining stratified rock, or the trap, or both. The waters of hot mineral springs have often produced metamorphic effects in the rocks, and many mineral species have been formed by this means.

Regional Metamorphism. — In regional metamorphism, the regions undergoing change have often been thousands of square miles in area, and the depth to which the alteration has extended has sometimes exceeded 30,000 feet. The rocks were originally, in great part, uncrystalline limestones, shales, sandstones, conglomerates. They are changed to crystalline limestone or marble, quartzite, gneiss, mica schist, and the like. They were originally in horizontal strata; they are now upturned or folded, and are often intersected by veins.

New England is mostly covered by metamorphic rocks; and they spread over the eastern border of New York, to Manhattan Island. They occur in the Adirondacks, and over a large area in Canada; in the Highlands of New Jersey and Putnam County, New York; in the Blue Ridge and the Black Mountains, and the Piedmont region east of those mountains; in a large area south of Lake Superior; in high ranges along the summit of the Rocky Mountains; and in the Sierra Nevada in California. They occur also in Scotland, Wales, Cornwall, Scandinavia, and various other regions.

In some cases, conclusive proof that such crystalline rocks are metamorphosed stratified rocks is afforded by the occurrence of unobliterated fossils, in some portions of a metamorphic stratum, where the change is least complete: as in part of the marble of West Rutland and other places in Vermont; in the limestone and schists near Poughkeepsie and elsewhere in Dutchess County, New York, and near Bernardston, Massachusetts; in the Sierra Nevada; in Norway; in the Alps; and in several other localities in Europe.

In other cases, a sedimentary origin has been inferred

Often, however, the material derived from the wear of gneiss and granite and other rocks is not only pulverized, but also more or less decomposed. The feldspar, for example, may have lost its alkalies, or the mica its oxide of iron and alkalies; and in such a case the process of metamorphism cannot, of course, restore the original rock. The new rock made can contain no feldspar or mica, if the alkalies have been wholly removed, but it may turn out an argillite or slate; or, if much oxide of iron and magnesia are present, a hornblende rock, or a chlorite rock, or some other kind from which the alkalies, potash and soda, are absent.

4. FORMATION OF VEINS.

Nature and Origin of Spaces occupied by Veins. — Veins, like dikes, are fillings of spaces in the rocks; but they differ from dikes in the manner in which the filling has taken place. Dikes, as explained on page 188, are fissures filled with igneous rock injected in a state of fusion. The mode of formation of veins will be explained later.

The spaces filled by veins are usually cracks or fissures made (1) by uplifting or disturbing forces; (2) by the expansion or pressure of vapors; (3) by shrinkage from cooling or drying; they may be (4) openings between the layers or laminæ of a rock produced in the flexing of the beds, like those between the leaves of a quire of paper when folded over; or (5) open spaces made in rocks by solution, as caverns are made.

The uplifting and flexing of rocks which have resulted in fissures and openings, are often accompaniments of metamorphic change, and the fissures may have become filled before the era of metamorphism had passed. The heat concerned in such a case may be, as explained above, that derived from the movements in the strata, in connection with that of the earth's depths.

Veins are large or small, deep or shallow, single or like a complex network, according to the character of the argillaceous rock, made from the disintegration of granite, gneiss, and related rocks, is changed to granite or gneiss again. Grains of pyroxene may be changed into hornblende, the two minerals being substantially identical in chemical composition, though differing in crystalline form.

7. In many cases, a change of constitution; for the ingredients subjected to the metamorphic process often enter into new combinations; as when a limestone, with its impurities of clay, sand, phosphates, and fluorides, gives rise, under the action of heat, not merely to white granular limestone, but to various crystalline minerals disseminated through it, such as mica, feldspar, scapolite, pyroxene, apatite, chondrodite, etc.

It is thus seen that metamorphism may fill a rock with crystals of various minerals. Even gems are often among its results. What is of more value, it makes out of rude sandstones and limestones crystalline rocks, as granite and marble, for architectural and other uses. Man's imitations of nature are seen in his little red bricks.

Process. — The principal agencies in metamorphism are *heat*, *water*, and *mechanical action.*

Heat is important: (1) in order to produce that weakening of cohesion among the particles of a rock which is the preparatory step toward a recrystallization; and (2) in order to bring about the chemical changes that are required, nearly all demanding a higher than the ordinary temperature, though less than that of complete fusion.

Water is important because: (1) dry rocks (as illustrated in a fire-brick) are bad conductors of heat; (2) it helps greatly in the weakening of cohesion; (3) it takes up silica and alkali from all rocks containing feldspar (page 187), if heated (and little heat is necessary), and thus becomes a siliceous solution, which, on cooling, may deposit the silica as a cement among the grains of the rock, and so promote its solidification — as in altering sandstone to quartzite, — and may also deposit quartz in cavities or fissures; (4) at higher temperatures, in the

Materials of Veins. — Quartz is the most common, because siliceous solutions are easily made, requiring little heat. Granitic material, requiring higher heat, is also common, but especially in veins intersecting the more crystalline rocks; and vein granite is usually much coarser in crystallization than ordinary granite. Other materials of frequent occurrence are calcite, barite (barium sulphate) and fluorite (calcium fluoride); but, where these occur, quartz may also be present. Along with the earthy minerals may occur gold, or various ores of copper, lead, silver, and other metals, besides pyrite (iron sulphide), which is almost universally present in ore-bearing veins, or lodes. The earthy minerals are called the gangue of the ore.

Many veins have a banded structure, like Figs. 204 and 205. Metallic veins, especially, are often thus banded, and have the ores lying in one or more bands alternating with other bands consisting of different minerals or rock material.

In Fig. 204, representing a vein at Valparaiso, the bands numbered 1, 3, and 6 are quartz; the others are granite. In Fig. 205, representing a vein at Godolphin Bridge, Cornwall, *a* is a band of quartz, *b*, *b* are bands of agate, *c* is crystallized quartz, *d* is chalcopyrite mixed with quartz.

Origin of Vein Deposits. — The material of veins has been deposited from solutions or vapors. The solutions or vapors are generally hot. This is always the case in large veins, or in veins extending down to any considerable depth. Such veins may be divided into two classes, according to the source of the heat.

1. *Where the Heat is not Derived from Eruptions of Igneous Rock.* — Such veins are apt to occur in regions of metamorphic rock; and the heat, like that in regional metamorphism, is the result of movements in the earth's crust, or is the general heat of the interior of the globe. In this class are included nearly all veins of quartz and

free silica to make opal or quartz; and, in some tufas of California and Colorado, the clustered tree trunks of a former forest, as well as scattered logs and stumps, have been petrified by silica from such a source.

Pressure is requisite for most metamorphic changes. Limestone heated without pressure loses its carbonic acid and becomes quicklime; but, under pressure, as has been proved by experiment, the carbonic acid is not driven off. The needed pressure may be that of an ocean above; it may be that of the superincumbent rocks, and a few hundred feet would suffice.

Crustal movements have operated in metamorphism, partly by producing heat through the crushing of rocks, but also by producing rearrangement of the materials of rocks. The schistose structure, which is so characteristic of metamorphic rocks, is doubtless often produced in this way (*dynamic metamorphism*). Sometimes the crystalline plates of mica and other minerals are forced by pressure into a position at right angles to the direction of pressure; sometimes the rock has been sheared, and the crystalline plates drawn out along the planes of shearing.

The similarity of an argillaceous sandstone to gneiss or granite is often much greater than appears to the eye. When a sandstone has been made out of a gneiss, it may have the quartz, feldspar, and mica of the gneiss, merely pulverized, with little or no chemical alteration; so that the change produced in it by metamorphism may be mainly a change in state of crystallization. By simply heating a bar of steel, and cooling it slowly or rapidly, it may be made coarse or fine steel, the process causing the molecules of the small grains to unite into larger grains in the coarser kind, and the reverse for the finer. There is something analogous in the change, above described, of an argillaceous sandstone to gneiss or granite. It cannot be asserted, however, that the feldspar grains in the sandstone will always remain feldspar; they may contribute to the making of mica or some other mineral.

auriferous quartz veins, were often openings between layers of the slate made in the folding or upturning. Quartz veins are the usual original sources of gold; and the gold-bearing gravels, which afford the metal by simple washing, and have yielded the larger part of the gold in use, are the detritus made out of the gold-bearing rocks. The same gravels often afford platinum, iridium, and diamonds.

While fissures filled by this lateral inflow of material, in connection with emanations from the depths below, may be uniform in material across, as in many quartz veins, they may also consist of bands of different minerals, as in many metallic veins (Figs. 204, 205). In the formation of banded veins, the process has brought in for a while one kind of mineral, as quartz, and deposited it over the walls of the fissure; then, through some change, some other mineral or ore, as an ore of lead, or one of zinc, or one of copper; then quartz again, or fluorite, or calcite; and so on until the fissure was filled. In a normal banded vein the succession of bands from each side to the middle is identical or nearly so, as illustrated in Fig. 204. In the case shown in Fig. 205, the fissure appears to have been opened and filled at two different times, the band *d* being virtually a separate vein from the adjoining bands *b*, *c*, *b*.

The above is one of the methods by which the earth's precious metals have been gathered out of the rocks, in which they were sparingly disseminated, into generous veins, and thereby placed within reach of the miner.

2. *Where the Heat is Derived from Eruptions of Igneous Rock.* — (*a*) Dikes of porphyry, dolerite, and related rocks sometimes determine the courses of veins of metallic ores. The veins are generally situated near the walls of the dike, and either in the igneous rock or in the rock adjoining.

The veins (1) may have been made when the dike was made; or (2) they may occupy fissures made subsequently, but during the same epoch of disturbance; or (3) they may have been formed later, the old plane of fracture being a plane of weakness liable to be opened anew. The metallic materials of the vein have been brought up as solutions or vapors, either from the depths that afforded the igneous rock itself, or, more probably, from the walls of a deep part of the fissure.

The veins of native copper at Keweenaw Point, those containing ores of the same metal in the red sandstone (Triassic) of the Connecticut Valley, New Jersey, and Pennsylvania, those of silver ores in Nevada and other localities along the Rocky Mountains and Andes, thus originated — that is, in connection with igneous ejections; the ores not coming up as a constituent part of the igneous rock, but through the agency of vapors and subterranean waters.

(*b*) Frequently, in regions of igneous ejections, fissures have been made that have received not igneous rock, but only vapors or mineral solutions from below, and thus have become metallic veins. Each of the regions just mentioned contains examples of such veins.

The filling may continue in progress long after the igneous rock is cooled, or as long as hot water or vapor continues to rise through the fissure. Shrinkage cracks and other openings in the rock adjoining the fissure may spread the mineral depositions widely on either side. The vent may continue as a source of heat to surface waters, making hot mineral springs and steaming pools or basins, about or from which deposits may take place of a veinlike character, as is going on now in Nevada and California.

Superficial Veins. — Besides the veins thus far considered, which occupy fissures extending to some considerable depth, and whose formation involves the action of heat in considerable degree, there are numerous small superficial veins which may have been formed without any considerable elevation of temperature. Shrinkage cracks and other small cracks in rocks have been filled with calcite or other minerals brought in by infiltrating waters from the immediate vicinity.

Depositions of galenite, or lead ore (sometimes with zinc ores), have taken place in cavities or caverns in limestones, as in Wisconsin, Illinois, and Missouri. In these deposits, the source of the ore is somewhat uncertain; but it is apparently derived from the concentration of ores which had been diffused through the sedimentary strata, since the cavities do not have the character of fissures extending to great depths. Such deposits often have great extent, and are a valuable source of ore, as in the localities mentioned. During the deposition of the ores, the limestone underwent much corrosion from acid solutions concerned in or resulting from the process.

Many cases of extensive bodies of ore in cavities in limestone appear not to be of the above-mentioned kind, but to be vein deposits of the ordinary sort. They may in some cases have originated in fissures which produced ore deposits only where they intersected limestones, because only limestones were easily rendered cavernous by the corroding waters or vapors, so as to afford spaces for the ores.

So-called Veins that are not True Veins. — In the course of the earth's rock-making, metallic ores have often been deposited along with the detritus when a sedimentary bed was in progress of formation; they have been brought into marshes, or spread over confined sea margins and mud flats, by running waters which took up the metal (in some soluble state of combination) from the decomposing rocks of the region around. Deposits of iron ores are thus made at the present time (page 116), and ores of zinc, cobalt, nickel, and copper were so deposited in early geological ages. When strata containing such metalliferous layers have undergone uplifts and crystallization, the nearly vertical beds look like veins. Many of the great deposits of hematite and magnetite in the Archæan terranes are probably beds, not veins nor dikes.

Wide cracks opening to the surface have sometimes been filled with sand or earth. Such deposits have sometimes granite, whether containing metallic ores or not, and most banded mineral veins. The fissures or openings are a result of profound disturbances, such as give rise also to metamorphism. The material of the vein is brought into the opening either from the rocks directly adjoining, or from those of depths below. The fissured rocks being heated, as above stated, all water or vapor present tends to decompose the rock material near the fissure; it takes alkalies from the feldspars, and so becomes siliceous, and few minerals will withstand its action. The water or vapor presses into the fissures or openings, carrying the mineral material it can dissolve, and depositing it; and it keeps on supplying material until the fissure is filled or the supply of material is exhausted. It is natural that veins in gneiss and mica schist filled in this way should often be granitic veins, for these rocks contain the quartz, feldspar, and mica of granite; and that they should often be quartz veins simply, which they are likely to be if the temperature is not high enough to make or dissolve feldspar and mica. The veins of extremely coarse granite, or pegmatite, appear to be in origin somewhat intermediate between ordinary veins and dikes. Under the joint action of heat and water, the material was probably in a condition somewhat intermediate between fusion and solution. The various phases of aqueo-igneous fusion form, in fact, a complete series of gradations between fusion and solution.

Under the action, whatever metallic ores or constituents of gems the fissured rock contains, are carried into the fissure with the other mineral material; and additions may be received largely through solutions or vapors rising from its deeper parts.

By such means veins have been supplied with their gems and ores. The quartz veins in the slate rocks of a gold region have in this way become gold-bearing veins, the gold and quartz having been brought in by the same moisture, and both having been gathered from the adjoining or underlying rocks. These openings, in the case of has been said to occur in connection with great crustal movements (p. 195); but no explanation has been given of the cause of those movements.

6. *Earthquakes* have been stated to result from fractures of rocks in subterranean regions, consequent (1) on undermining by the solvent action of water (page 144), or by the extrusion of lava (page 184); or (2) on the explosions attending volcanic action (page 182).

But none of the causes that have been considered explain the great changes of level involving large parts of continents or of oceanic areas; or the phenomena attending the making and uplifting of mountain ranges; or the earthquakes that have shaken a hemisphere.

Relation in Size between the Earth and its Surface Features. — On a globe twelve feet in diameter, the height of the earth's loftiest mountains would be represented by an elevation of about one tenth of an inch; the whole difference of level between the deepest part of the oceanic basin and the highest point of the land, by twice this amount; and the mean depth of the ocean, by a depression of one nineteenth of an inch. The deformation of the sphere produced in the making of the continents and mountains was, therefore, very small.

Probable Condition of the Earth's Interior. — It is almost certain that the central portions of the earth are now solid. The enormous pressure in those central portions would raise the melting point far above any temperature which can be supposed to exist there. Indeed, it is probable that when the material of the globe first aggregated itself together, the central portions were already solid from the effect of pressure, so that the earth has never been completely liquid. Whether there is now, as presumably there once was, a liquid stratum between the solid nucleus and the solid crust, is a question on which there is much difference of opinion.

It is urged by many physicists, though not by all, that the earth has become solid throughout, as solid as steel;

metallic materials of the vein have been brought up as solutions or vapors, either from the depths that afforded the igneous rock itself, or, more probably, from the walls of a deep part of the fissure.

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onward; no mountain borders for the continents; no general system of feature lines for the globe.

The facts would appear, therefore, to prove that, if a liquid or plastic subcrustal layer exists, the crust must be thick enough to possess some considerable degree of rigidity. And, probably, whatever the condition of the plastic layer underneath the crust may have been in past time, only mere remnants of it now exist, the greater part of it (if not the whole) having become solid.

On the supposition that the liquid subcrustal layer which once existed has mostly solidified, there must still remain, at no great depth, a zone where the temperature is just below the melting point, and where fusion would be produced by any local diminution of pressure or increment of heat, such as might result from movements of the crust. Such regions of liquefaction may furnish the supplies for volcanoes and other forms of igneous eruption.

Evolution of the Earth's Fundamental Features.

Whether its interior be substantially solid, or extensively liquid, the earth is believed to be capable of adjustment to gravitational pressure through molecular flow, and to owe its shape primarily to the principle of gravitational equilibrium. The condition of equilibrium to which gravitation tends to reduce the earth has been called by Dutton *isostasy*.

Origin of Continent and Ocean. — The greatest inequalities of the earth's surface — continental plateaus and oceanic basins — are probably dependent on the principle of isostasy. Observations on the force of gravity in different localities appear to show that the materials underlying the oceans are denser than those underlying the continents. The downward pressure on the oceanic radii may thus equal that on the continental radii, the denser material compensating for the inferior height of the column.

On this view, the distinction between the continental been called *false veins*. They have the character of neither veins nor dikes, though both these names have been applied to them.

VI. CRUSTAL MOVEMENTS; EVOLUTION OF CONTINENTS AND MOUNTAINS.

Explanations already given. — In the preceding chapters the origin of many geological phenomena, and of some of the earth's features, have been briefly explained.

1. *Changes of level* have been described as caused (1) by change of temperature, this cause producing the expansion and contraction of rocks (page 172); (2) by undermining due to subterranean water (page 144); (3) by undermining due to volcanic outflows (page 184).

2. *Mountain forms* have been described as often a result of the sculpturing of elevated plateaus of nearly horizontal rock by streams, as exemplified among some of the most majestic mountains of the globe (page 133).

3. *Folding of beds* has been shown to have been caused, when they are clayey, soft, and wet, by a lateral movement produced through the pressure of superincumbent material (page 146).

4. *Fractures and faultings of strata* have been attributed (1) to undermining by different methods (pages 144, 184); (2) to contraction or expansion by change of temperature; (3) to shrinkage on drying, producing deep or shallow fractures (page 174); (4) to the expansive force of vapors (page 182); (5) to the hydrostatic pressure of a column of lava (page 180); and to other causes.

5. *Metamorphism* has been described as produced on a small scale, (1) in the vicinity of dikes of igneous rock, through the heat of the rock when it was cooling from fusion, if vapors or moisture were present to aid (page 190); and (2) in the neighborhood of hot springs (page 191). Metamorphism on a large scale (regional metamorphism)

foldings of strata, earthquakes, mountain-making, became eminently features of the continental borders, and most prominently so of the borders which face the largest oceans.

Continental Evolution, as illustrated in North America. — The two systems of forces engaged in the progress of North America were those from the direction of the Atlantic and the Pacific basin — the latter the greater. Under their action the V-shaped Archæan area (see map, page 237) was first defined, one branch stretching northeastward to Labrador and the other northwestward to the Arctic seas, and thus facing respectively the Atlantic and Pacific areas, while linear areas of Archæan rock extend, in a series approximately parallel with the eastern arm of the V, from Newfoundland to Georgia, and, in another series approximately parallel with the western arm of the V, along the course of the western Cordillera. It follows from the courses of the arms of the V, and of the other Archæan areas, that the Atlantic force acted mainly from the southeastward, and the Pacific from the southwestward, and the two, therefore, nearly at right angles to one another. It is also apparent that the Pacific force even then was the greater, and hence the Pacific Ocean the larger; for the northwestward branch of the V is far the longer.

Thus the Archæan nucleus was outlined, and the position of Hudson Bay determined within the arms of the V. From this nucleal dry land progress went forward southeastward, or toward the Atlantic, and southwestward, or toward the Pacific, successive formations being added, and the dry land gradually extending (though with many oscillations) under changes of level caused mainly by the same forces.

Then, when the Lower Silurian closed, appeared the mountains of the Taconic system; and, when Paleozoic time was closing, appeared the Appalachian system, parallel to the eastern branch of the Archæan heights.

Again, on the Pacific side, other ranges were made, parallel to the course of the Rocky Mountain chain; among them — after the Jurassic era, the Sierra Nevada; after the Cretaceous era, the ranges of the Laramide system; and, still later, Tertiary ranges toward the coast, each epoch adding new parallels to the western branch of the Archæan nucleus. Finally, in the course of the Tertiary era, occurred the vast geanticlinal movement in which the mass of the Rocky Mountains rose to its full height above the ocean.

Each added range, as is seen, proves that the mountain-making forces continued to act to a large degree from the same directions as in Archæan time.

Thus the continent made progress, adding layer after layer to the rocks over its surface, and range after range in parallel lines to its heights, until finally the continental area reached its limit, and the great interior basin had its mountain borders completed : on the side of the Atlantic, the low Appalachians; on the side of the Pacific, the massive and lofty Cordillera.

On this view, the evolution of the features of the surface went forward through one system of forces originating in one single cause — the earth's contraction from cooling. North America, which is here appealed to for explanations, affords the truest and clearest illustration of the principles involved in the system of evolution, because it lies alone between the two oceans. The progress on this account went forward with great regularity, each age repeating the preceding in the direction of all oscillations or uplifts. It was a single isolated individual making systematic progress throughout until its final completion, and exhibits truly the system in the earth's development, whatever the true theory of that development. Europe, in contrast, has Africa on the south and Asia on the east; it is, therefore, full of complexities in its feature lines, and in the succession of events that make up its geological history.

Structure of Mountain Ranges.

It has already been stated that mountain-making movements result from the compressive force exerted upon the crust of the globe by reason of the cooling and consequent contraction of the hot material beneath; and that in general that force manifests itself most conspicuously near the continental borders as a thrust from the direction of the oceans. Before giving more detailed explanation of the process of mountain-making, it is necessary to give some account of the characteristic structure of mountain ranges.

Range, System, Chain, Cordillera. — A mountain range includes all the ridges resulting from a single orogenic movement — that is, in general, as will be explained hereafter (page 216), the structure resulting from the crushing and upfolding of a single geosyncline. Ranges are the individuals or units in mountain structure.

A mountain system includes all ranges in any one region made in different, more or less independent, geosynclines, at the same epoch. Thus the Appalachian range, the Acadian range in Newfoundland and Nova Scotia, and the Ouachita range in Arkansas and the Indian Territory, form together the Appalachian system.

A mountain chain is a combination of approximately parallel ranges or mountain systems of different epochs. Thus the Appalachian chain is the whole mountain border of the Atlantic side of North America — including highlands of Archæan age, the Taconic system of mid-Paleozoic age, and the Appalachian system of post-Paleozoic age.

A combination of two or more mountain chains constitutes a cordillera. The complex mass which includes the chain of the Rocky Mountains on the east, and the Sierra Nevada and the Coast ranges on the west, is an example of a cordillera.

The study of the structure and history of a mountain range gives, then, an understanding of the whole subject, since systems, chains, and cordilleras involve only repetition of ranges. The subject will be illustrated chiefly from the Appalachian range, extending (under various names) from New York to Alabama—a typical and classical example of mountain structure.

Thickness of Strata. — A marked characteristic of mountain structure is the immense thickness of the strata. The Paleozoic strata of which the Appalachians are built have a thickness of 30,000 to 40,000 feet, while the strata of the same age in parts of the Mississippi Valley do not exceed one tenth of that thickness. Moreover, these strata were all formed in water of no great depth, showing that during their deposition occurred a progressive subsidence to a depth more than twice the mean depth of the ocean.

Disturbed Condition of the Strata. — The following are among the characteristic features of the Appalachian region: —

1. Strata have been upraised and flexed into great folds, some of the folds a score or more of miles in span.

2. Deep fissures of the earth's crust have been opened, and faults innumerable have been produced, some of them of 10,000 to 20,000 feet.

3. Rocks have been consolidated; and, in the region of the Green Mountains, sandstones and shales have been crystallized into gneiss, mica schist, and other related rocks, and limestone into architectural and statuary marble.

4. Bituminous coal has been turned into anthracite.

Figs. 206–210 illustrate the folds and faults in the strata of the Appalachian range.

Figs. 206–208 represent sections in the coal regions of Pennsylvania. In Fig. 207, the Carboniferous beds are the uppermost beds at the left, numbered 14; the rest are beds of underlying Paleozoic formations, as explained under the figure.

Fig. 208 represents a section of the anthracite region between Nesquehoning Valley (on the west, left in section)

FIG. 206.

Section at Trevorton Gap, Pennsylvania, the dark bands representing coal beds.

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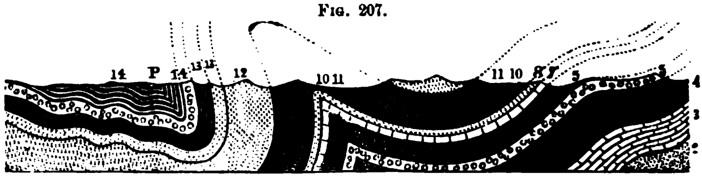

Section on the Schuylkill, Pennsylvania: P., Pottsville; 2, Cambrian; 3, 4, Lower Silurian; 5, Niagara; 7, Lower Helderberg; 8, Oriskany; 10, Hamilton; 11, 12, Upper Devonian; 13, Subcarboniferous; 14, Carboniferous.

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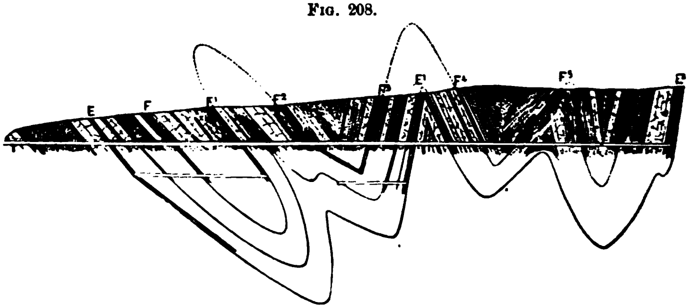

Section of the Panther Creek Anthracite basin at Nesquehoning tunnel.

anthracite and intervening strata of shale and sandstone; and the anthracite beds include the great "Mammoth bed" (lettered at its outcrop E, E^1, E^2) which is 13 to 27 feet thick, and the bed F (outcropping also at F^1, F^2, F^3, Again, on the Pacific side, other ranges were made, parallel to the course of the Rocky Mountain chain; among them — after the Jurassic era, the Sierra Nevada; after the Cretaceous era, the ranges of the Laramide system; and, still later, Tertiary ranges toward the coast, each epoch adding new parallels to the western branch of the Archæan nucleus. Finally, in the course of the Tertiary era, occurred the vast geanticlinal movement in which the mass of the Rocky Mountains rose to its full height above the ocean.

Each added range, as is seen, proves that the mountain-making forces continued to act to a large degree from the same directions as in Archæan time.

Thus the continent made progress, adding layer after layer to the rocks over its surface, and range after range in parallel lines to its heights, until finally the continental area reached its limit, and the great interior basin had its mountain borders completed: on the side of the Atlantic, the low Appalachians; on the side of the Pacific, the massive and lofty Cordillera.

On this view, the evolution of the features of the surface went forward through one system of forces originating in one single cause — the earth's contraction from cooling. North America, which is here appealed to for explanations, affords the truest and clearest illustration of the principles involved in the system of evolution, because it lies alone between the two oceans. The progress on this account went forward with great regularity, each age repeating the preceding in the direction of all oscillations or uplifts. It was a single isolated individual making systematic progress throughout until its final completion, and exhibits truly the system in the earth's development, whatever the true theory of that development. Europe, in contrast, has Africa on the south and Asia on the east; it is, therefore, full of complexities in its feature lines, and in the succession of events that make up its geological history.

folds were probably 20,000 feet in height above the level of the ocean, or would have had this height if they had remained unbroken, while in fact the loftiest summits now are less than 5000 feet, and few exceed 3000 feet.

The following are some of the general truths connected with the uplifts and metamorphism in the Appalachian region: —

1. The strike of the strata, and the courses of the great flexures and faults, are approximately northeast, or parallel to the Atlantic border.

2. The anticlines generally have their steepest slope toward the northwest, or away from the ocean. This is shown in Fig. 209; and in Fig. 208 the western anticline is actually overthrown, so that its western limb is carried beyond the perpendicular.

3. The flexures are most numerous and most abrupt on that side of the Appalachian region which is toward the ocean, and the folding diminishes in intensity westward. There is seldom, however, a gradual dying out westward, the region of disturbance being often bounded on the west by one or more of the great fractures and faults, as in eastern Tennessee.

4. The consolidation and metamorphism of the strata are more extensive and complete to the eastward (or toward the ocean) than to the westward.

5. The change of bituminous coal to anthracite, by the expulsion of volatile ingredients, was most complete where the disturbances were greatest; that is, in the more eastern portions of the coal areas. The anthracite region of Pennsylvania (see map, page 292) owes its broken character partly to the uplifts and partly to denudation. To the westward the coal is first semi-bituminous, and then, as at Pittsburg, bituminous. In Rhode Island, where the associated rocks are partly true metamorphic or crystalline rocks, and the disturbances are very great, the coal is an extremely hard anthracite, and in some places

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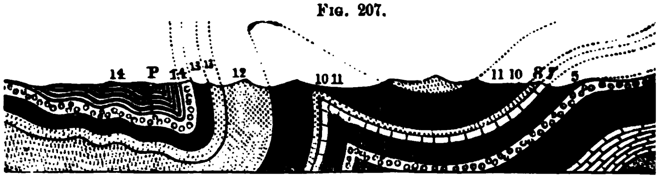

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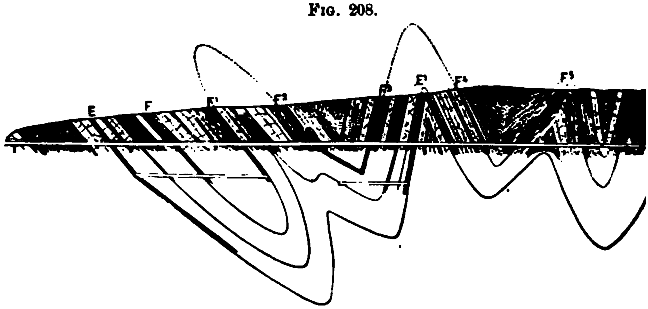

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sediments, in accordance with the principle of isostasy; but the gradual downward bending of the crust may be better explained as a result of the same lateral pressure to which the final catastrophe is due.

The Bottom of the Geosyncline weakened by the Heat rising into it from below. — As planes of equal temperature within the earth are approximately parallel to the surface, the accumulation of sedimentary beds in a sinking trough would occasion, as Herschel long since urged, the corresponding rising of heat from below, so that, with 30,000 feet of such accumulations, a given isothermal plane would be raised 30,000 feet. Under such an accession of heat, the rocks at the bottom of the trough would be greatly weakened. If the lower surface of the crust dipped down six or eight miles into a zone of plastic material beneath it, it would be actually melted off. Even on the supposition that the earth is completely solid, and no subcrustal plastic layer exists, the weakening of the geosyncline by the rise of the isothermal planes would be no less real. For, in the formation of the geosyncline, a great thickness of anhydrous, crystalline, refractory rock would be replaced by water-loaded sediments capable of suffering aqueo-igneous fusion (or at least pastiness) at a comparatively low temperature. The lateral pressure, acting against a trough thus weakened, would end in causing a collapse — that is, a catastrophic crushing of the trough, and a folding of the stratified beds within it. And with this the shaping of the mountain range would begin.

Character of the Mountain thus made. — Under such circumstances, the stratified rocks lying in the geosyncline or trough would be folded, profoundly broken, shoved along fractures, and pressed into a narrower space than they occupied before. The flexures were flexures in the strata that filled the geosyncline, not in the subjacent mass. They were simply anticlines and synclines, as distinguished from geanticlines and geosynclines (page 55). They became unequal-sided, as represented on pages 212, 213, and the mountain range itself inequilateral (pages 214, 216), because there was a pushing side in the mountain-making, the force coming mainly from one direction (the oceanic, in the case of the Appalachians). Such a mountain range, begun in a geosyncline, and ending in a catastrophe of displacement and upturning, has been named a *synclinorium*. (The word is from the Greek words from which syncline is derived, and ὄρος, mountain.)

On the side away from the chief source of movement, and beyond the profoundest faults, the elevations that have taken place have commonly made vast plateaus of nearly horizontal beds, like the Cumberland Mountain region of Tennessee and its continuation through western and northern Pennsylvania to the Catskill Mountain plateau of southern New York, on the outskirts of the Appalachian range. In such elevated areas, several thousands of feet above the sea level, and of wide extent, running waters have had their opportunity for sculpturing, and have thus made some of the most majestic mountain groups of ridges and peaks in the world. In Tennessee, the region of great folds and faults directly east of the Cumberland plateau was at first, beyond doubt, of far greater height than the plateau; but, owing to the vast amount of fracturing, as well as the less resistant character of the rocks, denudation has finally made it lower, and it is now the "Valley of East Tennessee," while the plateau is "Cumberland Mountain." Not less was the denudation in front of the Catskill plateau.

Metamorphism and other Attendant Effects. — The heat developed through the transformation of motion, added to that rising into the strata from below, would produce all the consolidation and crystallization — that is, all the metamorphism — which has been in any case observed, and on a scale as vast as that of the mountain range so developed. It gives a full explanation, therefore, of the origin of regional metamorphism.

is altered to graphite — an effect which may be produced in ordinary coal by the heat of a furnace.

These facts lead to the following conclusions: —

1. The movement producing these vast results was due to lateral pressure, the folding having taken place just as it might in paper or cloth under a lateral or pushing movement.

2. The pressure was exerted at right angles to the courses of the folds, as is the case when paper is folded in the manner mentioned.

3. The pressure was exerted from the ocean side of the Appalachians; for the results in foldings and metamorphism are most marked toward the ocean.

Fig. 211.

Upturned strata of the west slope of the Elk Mountains, Colorado. The light-shaded stratum, Jura-Trias; that to the right of it, Carboniferous; that to the left, Cretaceous.

4. The force was vast in amount.

5. The force was slow in action and long continued — not abrupt or paroxysmal, as when a wave or series of waves is thrown up by an earthquake shock on the surface of an ocean. For the strata were not reduced by it to a state of chaos, but retain their stratification, and show comparatively little confusion, even in the regions of greatest disturbance and alteration.

6. The action of the force was attended by the production of heat. For, without some heat above the ordinary temperature, it is not possible to account for the consolidation and crystallization of the rocks.

The characteristic features of mountain structure which lachian geosyncline, geanticlines were in progress both east and west of the subsiding area. In the eastern geanticline, the Atlantic border from New York southwestward beyond Virginia emerged, and continued apparently to be dry land until the middle of the Cretaceous. The western geanticline — the Cincinnati uplift — made two large islands in the mediterranean sea which then covered much of the continent, one in the region of Cincinnati, the other in Tennessee. The present altitude of the Appalachians, in spite of the enormous denudation they have suffered, is probably due in part to a geanticlinal movement which lifted the eastern border of the continent in the Tertiary era.

The Rocky Mountains, in the Cretaceous era, within the area of the United States, were 10,000 feet below their present level, the sea covering large areas over what is now the summit region (page 376). They were raised as a whole during the Tertiary, and it must have been through a broad and gentle geanticline. While the Tertiary mountain ranges were in progress, the part of the force not expended in producing them appears to have carried forward an upward bend, or geanticline, of the vast Rocky Mountain region as a whole.

As a mountain range resulting from the crushing of a geosyncline is called a synclinorium (page 218), a region raised to a high altitude by a geanticlinal movement may be called an *anticlinorium*. The same region may experience both kinds of movement in the course of its history. The Rocky Mountain region as a whole is an anticlinorium. Many of its component parts are typical synclinoria.

The movements over the continents in Cenozoic time were characterized in general by the vast areas of the regions affected. Great geanticlinal movements in the Tertiary gave to some of the great mountain chains a large part of their altitude. Areas of continental extent were involved in the oscillations of level which characterized sediments, in accordance with the principle of isostasy; but the gradual downward bending of the crust may be better explained as a result of the same lateral pressure to which the final catastrophe is due.

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Appalachian range were folded up; on the above estimate of the length of time, it occurred about 36 millions of years after the commencement of the Cambrian; so that the Appalachians were at least 36 millions of years in making, the preparatory subsidence having begun as early as the beginning of the Cambrian. Thus, whatever the mountain-making force, an exceedingly long time was required in order to accumulate a sufficient amount to produce a general yielding and plication or displacement of the beds, and start a new range of prominent elevations over the earth's crust.

the Quaternary. If Darwin's view of the formation of atolls is true (see page 103), the coral island subsidence — affecting an area in the Pacific over 5000 miles in its longer diameter — may well have been the counterpart of the vast geanticlinal movements over the continents in the later Tertiary and early Quaternary.

Eruptions of Igneous Rock. — The great fractures associated with mountain-making movements have often extended down to regions of molten rock, and given passage for eruptions. This seems to have been especially true in connection with the great geanticlinal movements of later geological time. The greatest lava floods of which we have evidence, as those of the Deccan and of the northwestern United States (page 189), belong to late Mesozoic or to Cenozoic time.

Such are the general steps of progress, and their explanations, according to that theory of mountain-making which attributes the movement to a lateral thrust in the earth's crust as a result of contraction in cooling. The universality of system in the features of continents and the characters of mountains has as yet no other probable explanation.

To obtain an adequate idea of the slow progress of the earth in the making of its mountains, it is necessary to remember that orogenic disturbances have taken place only after immensely long periods of quiet and gentle oscillations. After the beginning of the Cambrian, the first period of disturbance in North America of special note was that at the close of the Lower Silurian, in which the Taconic Mountains were finished; and, if time, from the beginning of the Cambrian to the present, included only 48 millions of years (page 444), the interval between the beginning of the Cambrian and the uplift and metamorphism of the Taconic Mountains was at least 20 millions of years. Another epoch of disturbance was that at the close of the Carboniferous era, in which the rocks of the tains thick strata of chalk; but in eastern North America the same formation exists without any chalk.

2. When rocks have been forming in one region, there have been none in progress in many others. Hence the series of strata serving as records of geological events is nowhere perfect. In one country one part may be very complete; in another, another part; and all have their long blanks — that is, large parts of the series entirely wanting. In New York and the states west to the Mississippi, there is only part of the lower half of the series. In New Jersey there is part of the lower half and part of the upper half, with wide breaks between. Over a large part of northern New York there exist only the very earliest of rocks.

3. The rocks of a country are to a great extent covered with earth or soil, so that they can be examined only at distant points.

4. The strata, in many regions, have been displaced, folded, fractured, faulted, and even crystallized extensively, adding greatly to the difficulties in the way of the geological explorer.

The following are the methods to be used in determining the true order of arrangement: —

(1) In sections of the rocks exposed to view in the sides of valleys or ridges, the order of superposition should be directly studied, and each stratum traced, as far as possible, through all the exposed sections.

When, through large intervals, a covering of soil or water prevents the tracing of the beds, other means must be used.

The order of superposition, when not directly observable, may often be inferred by observation of strikes and dips at the various accessible outcrops. For instance, a stratum dipping east must underlie another stratum with the same dip whose outcrop is farther east (unless the strata have been disturbed by faults or overturned folds).

The validity of the criterion of superposition is self-

PART IV.—HISTORICAL GEOLOGY.

Historical Geology treats of the order of succession in the strata of the earth's crust, and of the changes that were going on during the formation of each bed or stratum—that is, of the changes in the oceans and the land; of the changes in the atmosphere and climate; of the changes in the plants and animals. In other words, it is an historical view of the events that took place during the earth's progress, derived from the study of the successive rocks. It is sometimes called *stratigraphical* geology; but this term properly denotes only a description of the nature and arrangement of the earth's strata.

It has already been explained that the rocks of the earth's crust are historical records as to the past conditions of the earth's surface. In order that the records may afford an intelligible history, there must be some way of arranging them in their proper order; that is, in the order of time. The determination of this order is one of the first things before the geologist in his examination of a country.

Many difficulties are encountered.

1. The strata of the same period—called equivalent strata, because approximately equivalent in age—differ, even on the same continent. Sandstones and shales were often forming along the Appalachians in Pennsylvania and Virginia, when limestones were in progress over the Mississippi Valley. The Cretaceous formation in England con-

in eastern North America, although there is no chalk to be found there. In the same manner, the equivalents in America of the principal subdivisions of the rock series of Great Britain and Europe, Asia, and even Australia, are approximately ascertained; for this means of determination is a universal one, applying to the equivalency of rocks in different hemispheres as well as those on the same continent.

This method has its uncertainties. One continent may have received part of its species by immigration from another long after their first appearance in that other; and species may have survived in one continent long after they have become extinct in another. Moreover, especially in the later geological periods, the progress of evolution seems to have been more rapid in some regions than in others. The mammalian fauna of Australia at present consists almost exclusively of Marsupials and Monotremes. In a former geological period, the same was true of Europe and North America. Other continents have apparently outstripped Australia in the march of evolution. Again, there are doubts arising from the fact that, in any period, the life of one locality, even of marine animals, is very different from that of another, on account of differences in depth or purity of waters, muddy or rocky bottom, and temperature; and the range of terrestrial and fresh-water species is generally more local, and their value as criteria of age accordingly less, than that of marine species. The removal of all doubts, and the determination of the exact parallelism of the minor subdivisions of the geological series in different continents or distant parts of the same continent, are not to be looked for. Yet, by proceeding with care, and using not isolated facts, but the whole range of evidence afforded by the fossils, animal as well as vegetable, the general chronological order may be determined with a satisfactory degree of approximation.

The chronological order of events recorded in the various strata being determined by the methods already evident. The overlying stratum must be newer than the underlying. But it is obvious that this criterion is only applicable within a single district. For the comparison of the age of rocks in different regions, some other means are necessary.

(2) The aspect or composition of the rock may help to determine which strata are identical. But this method should be used with great caution, for the reason already stated — namely, that rocks made at the very same time may be widely different; and, conversely, those made in very different periods may look precisely alike in color and texture. Within a small area, the resemblance of the rocks at two or more outcrops may often be satisfactory proof that they are really parts of the same stratum. But the value of this test diminishes rapidly as the distance increases. In one class of cases, the character of a rock affords unquestionable evidence in regard to its age. A rock including fragments of some other rock is necessarily later than that other rock.

(3) Fossils afford the most generally applicable means of determining the age of rocks. This is so because of the fact, already mentioned, that the fossils of an epoch are very similar in genera — if not also in species — the world over; and those of different epochs are different. The geologist, by studying the fossils of the several beds at any locality, learns what kinds are characteristic of each bed, and the order of succession. Then, by comparing the beds of different localities, he ascertains whether any are essentially alike in species, and therefore of like age or period; and from this determination he continues further his study of the order of succession. By pursuing this course, for all accessible localities in different countries, geologists have ascertained the characteristic kinds of fossils for the successive strata through the long series of formations; and the lists which have been thus made serve for the identification of strata in widely distant regions. By a comparison of fossils it was proved that the Cretaceous formation exists

ancient, and ζωή, life. It represents the earth's *ancient* history.

3. The next æon is characterized by the immense development of reptilian life, the class of Reptiles showing a greater number of species and of ordinal types, greater size, and higher grade of organization, than ever before or after. Birds and Mammals made their first appearance, but attained only a feeble development. Among plants, Gymnosperms were predominant in the early part of the æon, but Angiosperms became abundant in its closing era. This æon is called *Mesozoic time*, from the Greek μέσος, middle, and ζωή, life. It represents the earth's *mediæval* history. It may fitly be called the *Age of Reptiles*.

4. The last æon is characterized by the great development of Mammals among animals and of Angiosperms among plants. In the latter of the two eras into which it is divided, Man himself appeared as the crown of the animate creation. With the beginning of this æon, we find species introduced which have continued to the present time, whereas the species of the former æons are all (or nearly all) extinct. This æon is called *Cenozoic time*, from the Greek καινός, recent, and ζωή, life. It represents the earth's *modern* history.

Extensive upturnings of rocks in various regions mark the close of the three earlier æons, so that, in many localities, strongly marked unconformabilities separate the rocks of successive æons from one another. In North America, the elevation of the Appalachian mountain system marks the close of Paleozoic time, and the elevation of the Laramide mountain system, the close of Mesozoic time.

Paleozoic time is divided into five eras, Mesozoic time into three, and Cenozoic time into two.

The eras of *Paleozoic time* are the following: —

1. **Cambrian.** — In this era, the animals were exclusively marine Invertebrates, and the plants were exclusively Seaweeds.

2. **Lower Silurian, or Ordovician.** — In this era appeared

explained, it becomes possible to divide geological time into a series of ages, each of which is characterized by a particular stage in the earth's progress, and particularly in the evolution of life. The progress of the earth's history, like that of human history, has been continuous, the idea characteristic of one age being always foreshadowed in the previous age. The boundaries of the various æons, eras, periods, and epochs recognized in geological history are therefore necessarily in some degree arbitrary. In many cases a great and relatively rapid geographical change, as the elevation of a range of mountains, serves as a time boundary; and such changes are generally indicated, at least in the more disturbed areas, by unconformability in the strata.

Geological time is thus divided into four æons: —

1. In the rocks of the earliest æon, only doubtful traces of life are found. For a long time after the formation of the earth's crust, the high temperature must have rendered the existence of life impossible. Before the close of the æon, some low forms of vegetable and animal life doubtless appeared. But the rocks are in general more or less strongly metamorphic; and whatever fossils they may once have contained, have been entirely destroyed, or left in condition doubtfully recognizable. This æon is called *Archæan time*, from the Greek ἀρχή, beginning. It may be considered the earth's *prehistoric* age.

2. The rocks of the next æon reveal the fossil remains of an abundant fauna and flora. In the early part of the æon, the animals were exclusively marine Invertebrates. Before the close of the time, however, Insects, Fishes, and Amphibians became abundant, and a few Reptiles made their appearance in the closing period. At first, the plants were only Seaweeds; but plants of higher grade appeared later, and the closing era was characterized by a luxuriant development of Acrogens and Gymnosperms. Birds, Mammals, and Angiosperms were entirely wanting. This æon is called *Paleozoic time*, from the Greek παλαιός,

Fig. 212.

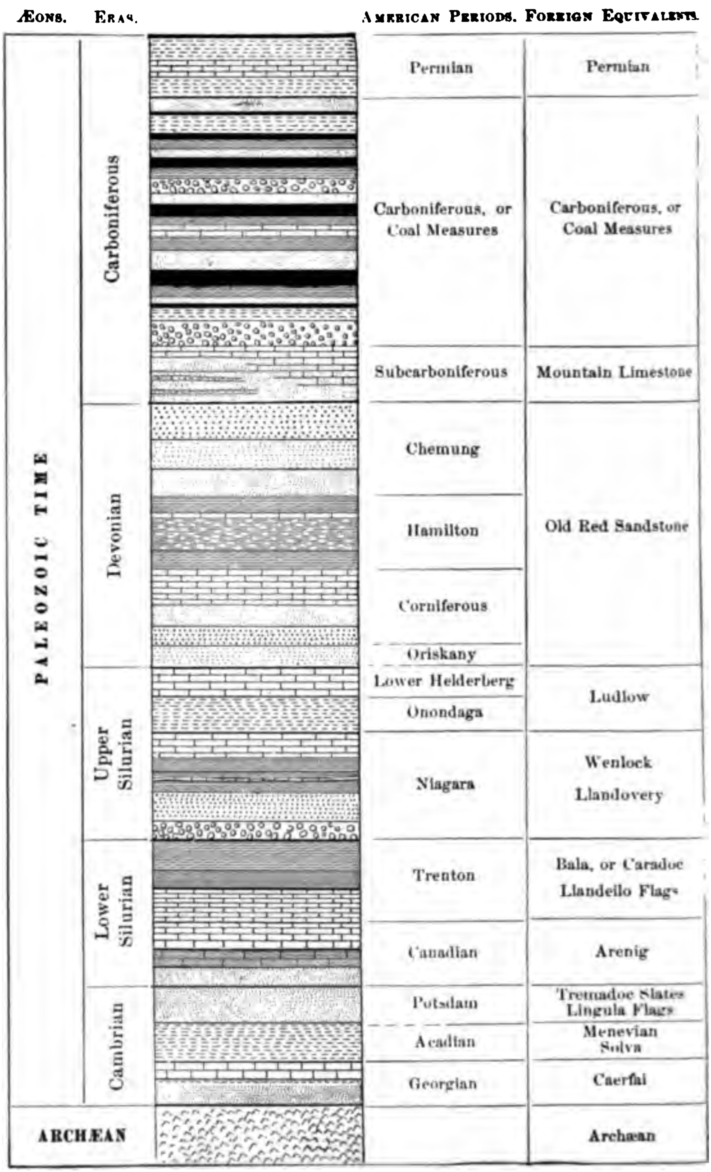
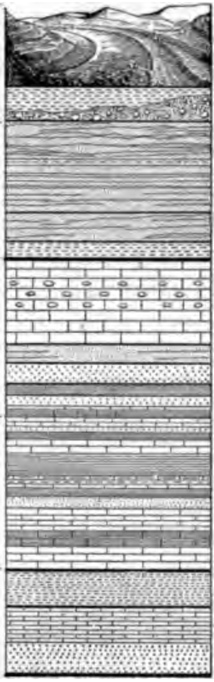

Æons.
Eras.
American Periods.
Foreign Equivalents.
PALEOZOIC TIME
Carboniferous
Devonian
Upper Silurian
Lower Silurian
Cambrian
ARCHÆAN
Permian
Permian
Carboniferous, or Coal Measures
Carboniferous, or Coal Measures
Subcarboniferous
Mountain Limestone
Chemung
Hamilton
Corniferous
Oriskany
Old Red Sandstone
Lower Helderberg
Onondaga
Ludlow
Niagara
Wenlock
Llandovery
Trenton
Bala, or Caradoc
Llandeilo Flags
Canadian
Arenig
Potsdam
Tremadoc Slates
Lingula Flags
Acadian
Menevian
Solva
Georgian
Caerfai
Archæan

FIG. 212 (*continued*).



ÆONS.	ERAS.	AMERICAN PERIODS.	FOREIGN EQUIVALENTS.
CENOZOIC TIME	Quaternary	Recent Champlain Glacial	Recent Pleistocene
	Tertiary	Pliocene	Pliocene
		Miocene	Miocene
		Eocene	Eocene
MESOZOIC TIME	Cretaceous	Upper Cretaceous	Upper Cretaceous
		Lower Cretaceous	Lower Cretaceous, or Neocomian
	Jurassic		Oölite Lias
	Triassic		Keuper and Rhætic Muschelkalk Bunter Sandstein

class culminated at the end of this era, or at the beginning of the next. Birds made their first appearance. Gymnosperms were the dominant type of vegetation.

3. **Cretaceous.** — The appearance of Angiosperms gave to the vegetation a modern aspect. Fishes of modern type (Teleosts) became abundant.

The eras of *Cenozoic time* are the following: —

1. **Tertiary.** — In this era there is still no evidence of the existence of Man. The Invertebrates were in large part of species which still exist, but the Vertebrates were all of extinct species. The Tertiary era may be called the *Age of Mammals.*

2. **Quaternary.** — Man himself, and other existing species of Vertebrates, made their appearance. The era may be called the *Age of Man.*

The successive strata in the formations of an era are very diversified in character, limestones being overlain abruptly by sandstones, conglomerates, or shales, or either of these last by limestones; and each may be very different from the following in its fossils. These abrupt transitions in the strata are proofs that there were great changes at times in the conditions of the region where the strata were formed, and the transitions in the kinds of fossils are evidence of great destruction at intervals in the life of the seas. Such transitions, therefore, naturally divide the eras into smaller portions of time, or *periods*, as they are called. By transitions similar in kind, but not so great, periods may generally be subdivided into still smaller parts, or *epochs;* and even the epochs often admit of still more minute subdivision.

The preceding summary of the life of the successive æons and eras will suggest to the student two important generalizations.

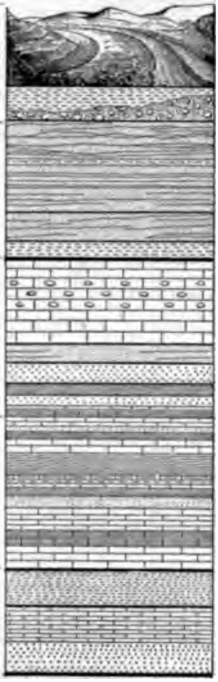
1. There has been a continuous approximation to the life of the present day, as shown, through all geological time by the increasing number of *classes* and other comprehensive groups identical with those now existing, and, finally, in Cenozoic time, by the gradual introduction of *species* that still survive.

2. There has been, on the whole, a progress from lower to higher forms of life.

These facts will be recognized as strikingly in harmony with that theory of the origin of species by evolution, or descent with modification, which is generally adopted by the naturalists of the present time. The subject will be discussed more fully when the student is in possession of the facts in some degree of detail.

The æons, eras, and periods recognized in American geology are exhibited in the following table: —

FIG. 212 (*continued*).



Eons.	Eras.	American Periods.	Foreign Equivalents.
Cenozoic Time	Quaternary	Recent Champlain Glacial	Recent Pleistocene
	Tertiary	Pliocene	Pliocene
		Miocene	Miocene
		Eocene	Eocene
Mesozoic Time	Cretaceous	Upper Cretaceous	Upper Cretaceous
		Lower Cretaceous	Lower Cretaceous, or Neocomian
	Jurassic		Oölite Lias
	Triassic		Keuper and Rhætic Muschelkalk Bunter Sandstein

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The eras of *Cenozoic time* are the following: —

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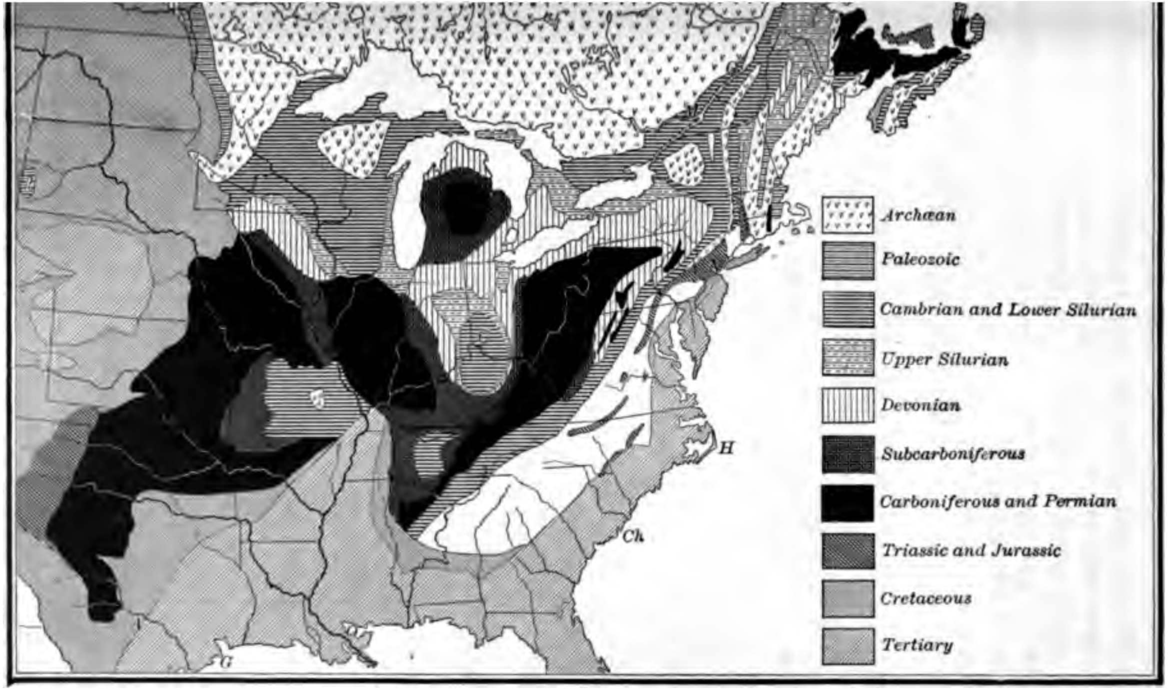
The ideal section on pages 230, 231, will further illustrate the succession of eras and periods, and will also indicate to some extent the European (especially British) equivalents for the divisions recognized in this country. The names of the periods in the first part of the section (those of the Paleozoic) are mostly derived from the names of American rocks or localities. The names in the other part are mostly European, as the series of rocks it includes (those of Mesozoic and Cenozoic time) is more complete in Europe than in America.

It will be observed that the same names are in use on both continents for the eras, and to some extent for the periods, since approximate correlations have been established for the larger divisions of geological time all over the world. It is, however, impossible to establish such correlations in regard to the smaller subdivisions. Hence, the names of periods to some extent, and of epochs and minuter subdivisions universally, differ in different countries and even in different parts of the same country. The names of several of the eras are derived from localities in Great Britain — a region in which the series of formations is displayed with remarkable completeness, and in which the study of stratigraphical geology was first developed. In somewhat analogous fashion, the American names of periods and epochs in the Paleozoic are in great part derived from localities in the State of New York — the series of Silurian and Devonian rocks in that state being remarkably complete, and having been thoroughly studied in the beginning of geological work in this country.

The map on page 235 represents the distribution of the rocks of the different ages, as surface rocks, over part of the United States and Canada. The areas indicated by the different kinds of shading are stated on the map. The areas left white are of unascertained or doubtful age.

Silurian strata may underlie the Devonian, and both



Geological map of part of the United States and Canada.

Silurian and Devonian may underlie the Carboniferous. The black areas of the Carboniferous period do not, therefore, indicate the absence of Devonian and Silurian, but only that the Carboniferous strata are the surface strata over the region.

I. ARCHÆAN TIME.

Archæan time, in geology, commences with the earth already a solid globe, or at least having a solid crust; for the conditions of only such a globe are within reach of geological investigation. There must have been an earlier time in which the earth was superficially liquid, and astronomy leads us back to the still more ancient time when the earth formed a part of the nebula of which the sun is the central residue.

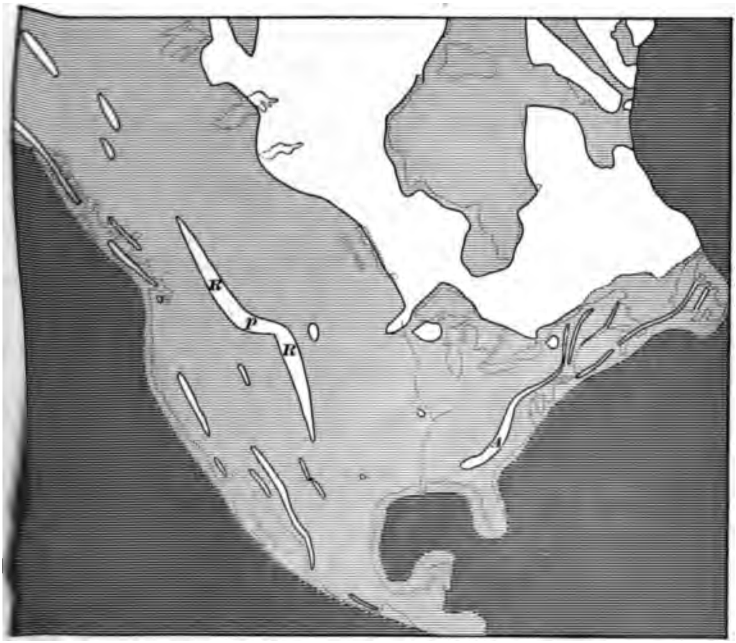
When the earth's crust was first formed, its temperature must have exceeded 2500° F. The atmosphere must then have contained all the water of the globe, all the carbon (in the form of carbon dioxide) now stored in solid form as coal and other hydrocarbon compounds and as carbonates, and various other materials which have since formed solid compounds. When the ocean was first formed by condensation from the atmosphere, its temperature may have been as high as 500° F., the atmospheric pressure being still perhaps 30 times as great as at present. The chemical action of the ocean in rock destruction and rock formation must then have been very much more important than in later times. Long ages must have elapsed before the earth was cool enough to permit the existence of the lowest organisms. Archæan time must have been immensely long.

ROCKS: KINDS AND DISTRIBUTION.

1. **Distribution.** — Since the Archæan era commenced with the origin of the earth's crust, Archæan rocks must extend around the globe, underlying all rocks of sub-

quent ages, and furnishing the material out of which most of these later rocks have been made. Over by far the larger part of the surface of the globe, they are concealed from view by subsequent formations. In North America they are surface rocks over a large area north of the Great Lakes, shaped like the letter V, the longer branch

FIG. 214.



Map showing areas of Archæan rocks in North America.

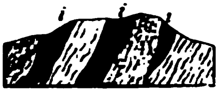
of which runs northwest to the Arctic Ocean, and the shorter northeast to Labrador. The large white area on the preceding map, in what is now British America, is the portion of the continent here referred to. Archæan rocks also appear in linear areas along the course of the mountain chains which form the borders of the continent. The longest of these areas in the east extends (though not without interruptions) from near the St. Lawrence to Georgia, appearing in the Green Mountains of Vermont and Massachusetts, the Highlands of New York and New Jersey, and the "Piedmont belt" of the South Atlantic states. Another may be traced from Newfoundland through Nova Scotia (with a submerged interval) to southeastern Massachusetts. In the west the most extensive area is that which forms the "backbone" of the Rocky Mountains. An isolated area appears in the Adirondacks, and another south of Lake Superior.

In Europe, Archæan rocks are in view in the great iron regions of Sweden and Norway, in Bohemia, and in Scotland.

2. **Kinds of Rocks.**—The rocks are mostly crystalline rocks, such as granite, quartz syenite, gabbro, gneiss, syenite gneiss, mica schist, hornblende schist, chlorite schist, and granular limestone. But besides these there are some hard conglomerates, quartzites, or gritty sandstones, and slates. The beautiful iridescent feldspar called labradorite (page 20) is a common constituent of some of the coarse crystalline rocks.

An abundance of iron is one characteristic of the beds. The rocks very often contain hornblende, an iron-bearing mineral, or black mica, also iron-bearing. There are in some regions immense beds of iron ore (*i*, *i*, *i*, in Fig. 215). In northern New York the beds are 100 to 200 feet thick. Similar iron ore deposits occur in New Jersey, in Michigan, south of Lake Superior, and in Missouri. Graphite is common in some places, and constitutes 2 to 30 per cent of some beds, especially of the limestones.

Fig. 215.



Iron ore beds, Essex County, New York.

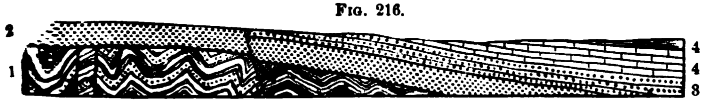
3. **Disturbance and Crystallization of the Rocks.**—The layers of gneiss and other schistose rocks, with the included limestones, are nowhere horizontal; but, instead of this, they dip at all angles, and are often flexed or folded

in a most complex manner. Fig. 216 represents the folded character of the Archæan rocks of Canada. The folded rocks in this figure are overlain by beds that are nearly horizontal, which belong to the Cambrian and Lower Silurian.

Owing to the dislocations and uplifts which the rocks have undergone, giving the strata often a nearly vertical position, the iron ore beds look like veins (Fig. 215); and even the strata of crystalline limestone have often a similar veinlike appearance.

4. **Origin of the Rocks.** — The indurated sandstones, quartzites, and slates are of course ordinary sediments which have undergone more or less of metamorphism.[1] The same is doubtless true of some of the gneisses and schists. But a considerable part of the gneisses are undoubtedly derived

Fig. 216.



From the south side of the St. Lawrence in Canada, between Cascade Point and St. Louis Rapids: 1, Archæan gneiss; 2, Cambrian; 3, Canadian; 4 *a*, *b*, Trenton.

from igneous rocks (see pages 30, 192). Even in the case of those schistose rocks which have been derived from stratified rocks, it is often impossible to determine whether the foliation corresponds to the original stratification, or is a structure superinduced by dynamic metamorphism (page 195). The materials which have crystallized into the Archæan rocks must have included not only mechanical sediments, but also chemical deposits (which, as remarked on page 236, must have been more important then than in later times), lava flows, and tufa beds. Some, at least, of the iron ore beds are doubtless metamorphosed chemical deposits (page 116).

[1] The limestones, quartzites, slates, and other rocks whose sedimentary origin is pretty certain, together with the associated igneous rocks, constitute the Algonkian system of the United States Geological Survey. In many localities, such rocks overlie unconformably the more highly crystalline granites and gneisses.

The granites, gabbros, and other massive rocks are probably for the most part plutonic, but such rocks may be in some cases only the extreme term of metamorphism.

The earliest rocks formed in Archæan time must have resulted from the solidification of the molten material of the globe. But it is unlikely that any of those primitive rocks are anywhere accessible to observation. Most of the visible Archæan rocks bear evidence of a derivative origin.

It is probable that, in the course of Archæan time, there were a number of epochs of extensive crustal movements accompanied by metamorphism, for instances of unconformability between one Archæan rock and another are frequent. Since a strongly marked unconformability everywhere separates the Archæan from later formations, it is inferred that the age closed with an epoch of very general disturbance.

Archæan rocks in general are more highly crystalline than those of later formations; yet there seems to be no definite lithological criterion which will distinguish rocks of that age from metamorphic and plutonic rocks of later times.

LIFE.

The graphite, abundant in some beds in Canada, is probable evidence of the existence of plants, since it is known that in later times graphite has been formed out of vegetable remains. The limestone beds suggest the idea that there was present either vegetable or animal life; for almost all limestones (see page 99) are of organic origin. But the inference in both cases is doubtful, since both graphite and limestone may have been formed by purely chemical processes.

No distinct fossil plants have been found, though general considerations render it probable that plants commenced before the close of Archæan time. The earliest plants were doubtless Seaweeds. No vegetable remains but those of Seaweeds are found in the overlying Cambrian strata.

Fig. 217 represents what has been regarded as a fossil animal, and named *Eozoon Canadense*. It is supposed to have been a coral-like mass made by Protozoans of the class of Rhizopods, the simplest of all kinds of animal life. The dark layers in the mass are supposed to mark the position of the soft part of the animals, while the white layers are supposed to be derived from their calcareous skeleton. The supposed animal nature of Eozoon is, however, probably a mistake. Structures of very similar appearance have been produced, where the supposition of organic origin is out of the question. Still, it is altogether probable that Rhizopods existed in the waters before the close of the Archæan era, and that they furnished material for beds of limestone. In some of the less strongly metamorphic rocks, supposed to belong to the later part of Archæan times, obscure and doubtful traces of animal fossils have been reported.

FIG. 217.

Eozoon Canadense.

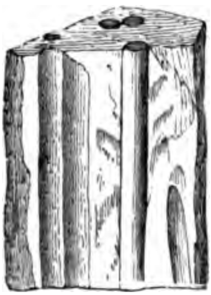
GENERAL OBSERVATIONS.

The large area of Archæan rocks shown on the map, page 237, represents the main portion of the dry land of North America at the close of the Archæan age; for it consists of rocks made during the age, and is bordered on its different sides by the earliest rocks of the next age. It shows the outline, approximately, of North America as it appeared when the Cambrian era opened. It was the nucleus around which in the course of time the continent grew. The smaller Archæan areas appear to

(*Orthoceras*) and forms with curved shells (*Cyrtoceras*); but not those with spiral shells, as *Nautilus*.

Worms. — The existence of marine Worms among the earliest animals of the globe is proved by the great numbers of worm holes or burrows in the sandstones, now filled with hard sandstone like that of the rock. They are very similar to the holes made by such worms in the sands of seashores at the present time. One species has been called *Scolithus linearis* (Fig. 230). These worm holes are common in the European as well as the American Cambrian sandstones. The minute toothlike bodies called Conodonts, found in the Cambrian, as well as in later formations, are probably jaws of Worms.

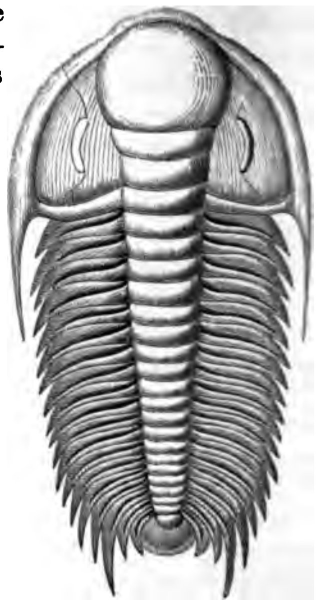
Fig. 230.



Worm: burrows of Scolithus linearis.

Arthropods. — One of the most characteristic groups of the Cambrian fauna was that of Trilobites, belonging to the class of Crustaceans. One of the largest of them, and a kind characteristic of the Acadian, or Middle Cambrian, is represented in Fig. 231, one third of the natural size. Its total length when living must have been about ten inches. The specimen figured was found at Braintree, south of Boston. Fig. 232 represents (natural size) a species characteristic of the Georgian, or Lower Cambrian. As

Fig. 231.



Trilobite: Paradoxides Harlani, × ⅓.

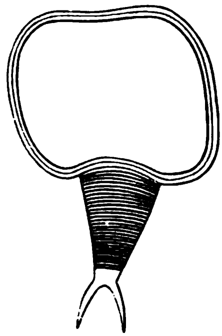
shown in the figures, both of these species had large eyes situated on the head shield.

Most specimens of Trilobites, as illustrated in these figures, fail to show antennæ, legs, or other appendages.

Fig. 232.

Trilobite: Olenellus Vermontanus.

Fig. 233.



Leptostracan: Protocaris Marshi.

A recent discovery of specimens of Trilobites in the Lower Silurian showing these parts (page 258, Fig. 253) has added much to our knowledge of the group.

Fig. 233 illustrates another group of Crustaceans (the Leptostracans) which was (like the Trilobites) eminently characteristic of the Paleozoic.

Brachiopods and Trilobites among animals, and Seaweeds among plants, make up the bulk of the living species thus far discovered. There is as yet no evidence that the hills bore a Moss or Lycopod, or harbored the meanest Insect, or that the oceans contained a single Fish.

GENERAL OBSERVATIONS.

The ripple-marks, mud-cracks, and tracks of animals preserved in these most ancient of Paleozoic rocks are records left by the waves, the sun, and the life of the period, as to the extent and condition of the continent in that early era. These markings teach that, when the beds were in progress, a large part of the continent lay at shallow depths in the sea, so shallow that the little currents made by the waves could ripple its sands; that over other portions the surface was a sand flat exposed at low tide; or a sea beach, the burrowing place of worms; or a mud flat, that could be dried and cracked under the heat of the sun, or in a drying atmosphere.

With such evidences of shallow water or emerged flats in a formation extending widely over the continent, it is a safe conclusion that the North American continent was at the time in actual existence, and probably not far from its present extent; and, although mostly below the sea level, and in some places somewhat deeply so, it was generally covered only by shallow waters, and probably nowhere submerged to truly oceanic depth. The same was probably true of the other continents. There is, in fact, evidence of other kinds which, taken in connection with the above, leaves little doubt that the existing places of the deep ocean and of the continents were determined even in the first formation of the earth's crust in early Archæan time, and that, in all the movements that have since occurred, the oceans and continents have never changed places.

This preservation of markings, seemingly so perishable, on the early shifting sands, is a very instructive fact. They illustrate part of the means by which the earth has been recording its own history. The track of a Trilobite, or the furrow left by the sweep of the wave over the sand, is a mold, in sand or earth, into which other sands are cast both to copy and preserve it; for, if the

The beds contain, in many places, ripple-marks (Fig. 185, page 154); mud-cracks (Fig. 189); layers showing the wind-drift, and the ebb-and-flow, structure (Figs. 161, 187); worm burrows (Fig. 230); and occasionally the tracks of some of the animals of the period.

In the Taconic Mountains of Vermont and Massachusetts, the Cambrian is represented by a great quartzite formation, with intercalations of mica and hydromica schist.

In southeastern Pennsylvania, the Lower Cambrian includes a great thickness of quartzite with overlying shales, or slates, and limestone; and besides these rocks there are, in South Mountain, large flows of basaltic and rhyolitic rocks.

The Keweenaw formation, south of Lake Superior, consisting of many thousands of feet of sandstone strata, with numerous intercalations of dolerite, felsite, and other igneous rocks, and bearing the remarkable deposits of native copper for which the region is famous (page 201), is very probably Cambrian, though it contains no fossils, and is considered by some geologists to be older.

In Great Britain the Cambrian rocks are hard sandstones and slates. The Lingula Flags are included in the Upper Cambrian. They are most extensively in view in North and South Wales and in Shropshire.

In Lapland, Norway, Sweden, and Bohemia, Cambrian strata have been observed. If the strata of later date could be removed from the continents, we should probably find the Cambrian beds extensively distributed over all the continents.

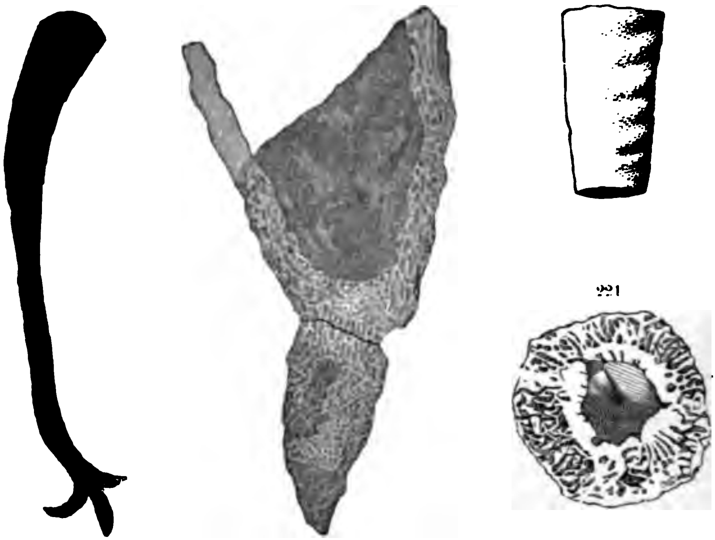
LIFE.

These most ancient of fossiliferous rocks contain no remains of terrestrial life. The plants of the period that left traces in the rocks were all Seaweeds. Among animals, all the Invertebrate subkingdoms except the Tunicates (which are destitute of skeletons) were represented by aquatic species, and by these only; there is no evi-dence that there were any Vertebrates.

It is remarkable that all of these subkingdoms were represented already in the Lower Cambrian. Moreover, among the Mollusks, both Lamellibranchs and Gastropods had already appeared. In the Middle and Upper Cambrian the species are mostly different from those of the

Figs. 218–221.

218 219 220



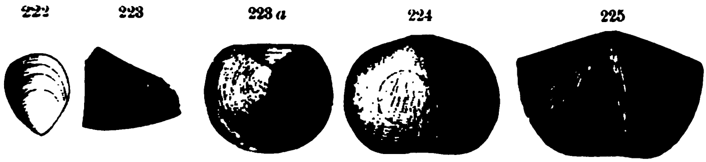
Sponge: Fig. 218, Leptomitus Zittelli. — Anthozoans: Fig. 219, Archæocyathus profundus; 220, 221, Spirocyathus Atlanticus.

Lower Cambrian, but they belong in general to the same groups. The most important step of progress during the Cambrian is the introduction of the class of Cephalopods — the highest class of Mollusks — in the Upper Cambrian.

Sponges; Cœlenterates; Echinoderms. — Fig. 218 represents one of the Sponges, and Figs. 219–221 represent two of the Corals of the Lower Cambrian. The Echinoderms were represented chiefly by Cystoid Crinoids. Fragments of Crinoidal stems are not uncommon.

Molluscoids. — Remains of Brachiopods are abundant. The Potsdam sandstone abounds in many places in a shell smaller, in general, than a finger nail, related to the modern *Lingula* (Fig. 222). Shells of genera related to

FIGS. 222–225.



BRACHIOPODS: Fig. 222, Lingulella prima; 223, a, Acrotreta gemma, × 4; 224, Orthis Highlandensis; 225, Orthisina (Billingsella) festinata.

Lingula are so characteristic of certain strata of the Cambrian as to have suggested the name *Lingula Flags*, or *Lingula Sandstone*.

Mollusks. — Figs. 226–229 represent some of the Mollusks of the Lower Cambrian. Especially noteworthy were the forms referred (though not without somewhat of doubt) to the Pteropods. The species of that group at present are few and small. In Cambrian times it was probably represented by numerous species, some of which were of considerable size. Some of the Cambrian Pteropods were peculiar in having the shell provided with a lid, or operculum. The Cephalopods of the Upper Cambrian include both forms with straight shells

FIGS. 226–229.

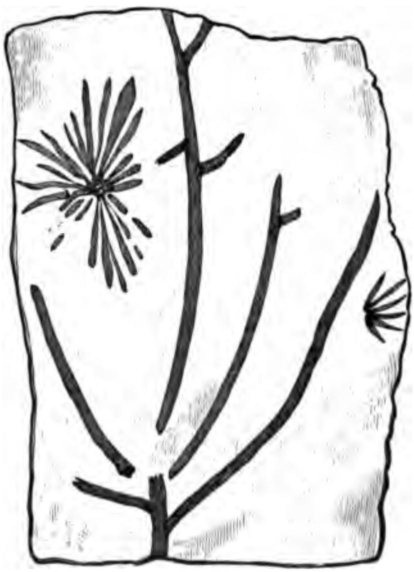
LAMELLIBRANCH: Fig. 226, Fordilla Troyensis, × 5. — GASTROPODS: Fig. 227, Stenotheca rugosa; 228, Platyceras primævum, × 4; 229, Hyolithes Americanus, × 2; 229 a, operculum of same, × 2.

overlain by the Llandeilo Flags. Above them there are the Caradoc Sandstone of Shropshire, and the Bala formation, the latter sandy slates and sandstone, with thin beds of limestone, in Wales. In Scandinavia the rocks are mostly shales, with some limestone, especially in the upper part of the formation.

LIFE.

The life of this era, like that of the Cambrian, was chiefly marine; but the era is remarkable as showing the first vestiges of terrestrial life, both vegetable and animal. The plants found fossil are mostly Seaweeds; but the Skiddaw Slates (included in the Arenig group) of Great Britain have afforded remains of a plant (Fig. 234) which has been referred to the Marsileaceæ, a group of the higher Cryptogams (Acrogens) allied to the Ferns and Lycopods.

Fig. 234.



Acrogen: Protannularia Harknessi.

All the subkingdoms of animals were represented (except the Tunicates), the earliest of Vertebrates belonging to this era. Moreover, Arthropods were represented not only by the aquatic Crustaceans, but also by the earliest Insects.

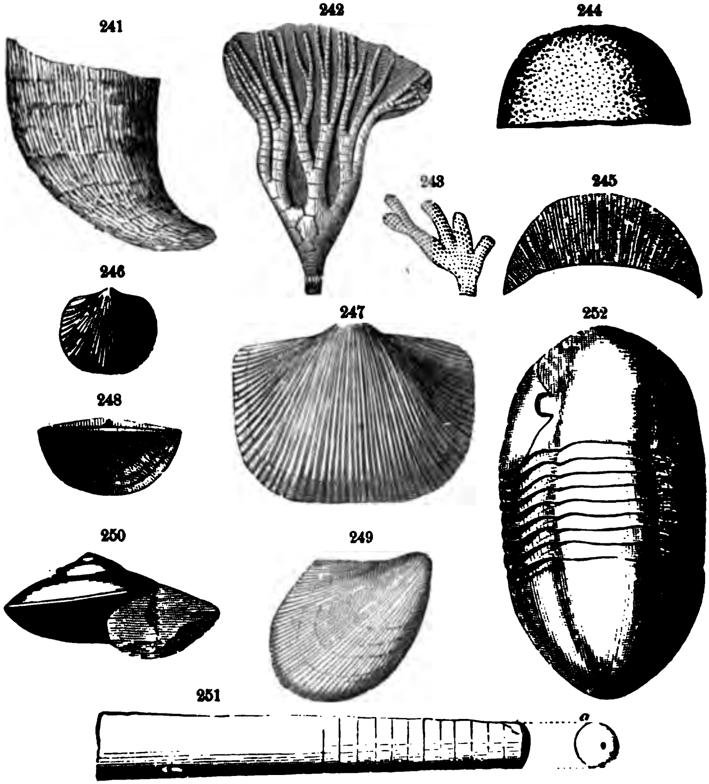
Cœlenterates. — The Lower Silurian beds, especially the finer shales and slates, are remarkable for the great waves or currents that succeed are light, they simply spread new sands over the indented surface, without obliterating the mold; and so the addition of successive layers only buries the markings more deeply, and thus protects them against destruction. When, finally, consolidation takes place, the track or ripple-mark is made as enduring as the rock itself.

The appearance in the Lower Cambrian of so many different groups of pretty highly organized animals, without any clear evidence of series of lower and more embryonic forms preceding them, is one of the most remarkable facts in geological history. It has been regarded by many as affording a strong objection to the theory of evolution. But it must be considered that the apparently abrupt introduction of the Cambrian fauna may be due to the imperfection of the record. Both animal and vegetable life was probably in existence during the latter part of the Archæan (page 240), though the general metamorphism of the rocks has destroyed or rendered unrecognizable whatever fossils may have been formed. The general unconformability between the Archæan and the Cambrian indicates an interval of time whose record is entirely lost (page 57). As it was a time of great geographical change, it may be supposed that it was a time in which evolutionary changes in fauna and flora were unusually rapid.

That most of the subkingdoms of animals should appear very early and almost simultaneously, is just what would be expected on evolutionary grounds. For it is not to be supposed that the subkingdoms were successively evolved in an ascending series, but most of them must have been independently evolved from ancestral forms almost as simple as Protozoans. Moreover, the fact that almost all groups of marine Invertebrates have larval forms which are minute, free swimming, and destitute of heavy skeletons, indicates that probably the ancestral forms from which they were derived were likewise minute, free swimming, and destitute of skeletons. Such forms would be

Crinoids, though the stem on which it stood is mostly wanting, and the arms are not entire. There were also true Starfishes in the seas.

FIGS. 241-252.



ANTHOZOAN: Fig. 241, Streptelasma corniculum. — CRINOID: Fig. 242, Taxocrinus elegans. — BRYOZOANS: Fig. 243, Stictopora acuta; 244, Prasopora lycoperdon; 245, section of same. — BRACHIOPODS: Fig. 246, Orthis testudinaria; 247, Orthis occidentalis; 248, Leptæna sericea. — MOLLUSKS: Fig. 249, Ambonychia bellistriata; 250, Rhaphistoma lenticulare; 251, Orthoceras junceum. — TRILOBITE: Fig. 252, Asaphus platycephalus, × ½.

Molluscoids. — Among Molluscoids, Bryozoans were very common. The fossils are small cellular corals: one is shown in Fig. 243.

II. Neopaleozoic Section.

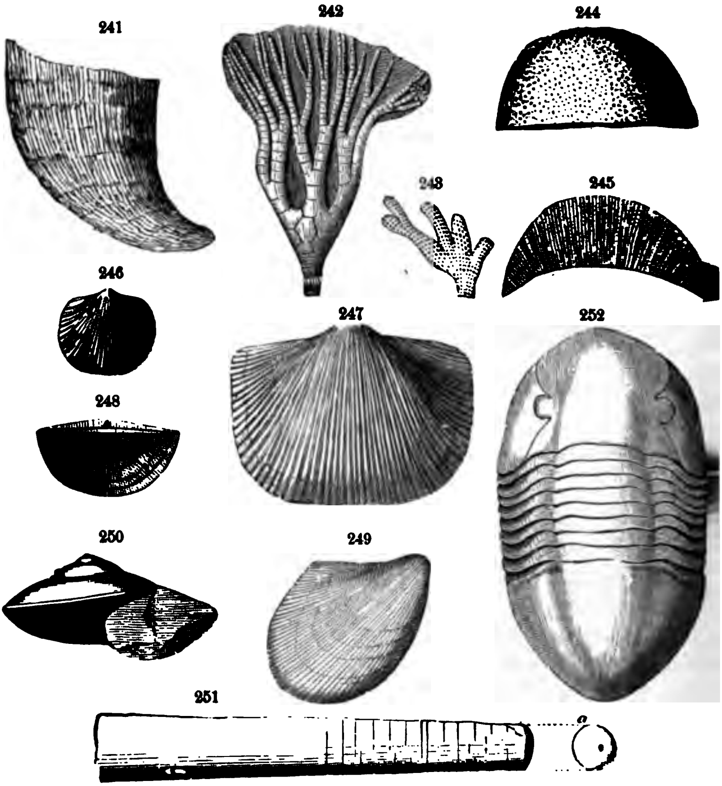
1. Upper Silurian Era.
2. Devonian Era.
3. Carboniferous Era.

The prefixes used in forming the names of the two sections are derived, respectively, from ἠώς, dawn, and νέος, new. The boundary of the two sections is defined, in eastern North America and western Europe, by an epoch of mountain-making, and consequently by extensive unconformability in the strata. The Eopaleozoic section, or Age of Invertebrates, was marked by a rich and varied display of marine invertebrate life, but only the scantiest beginnings of Vertebrates and of terrestrial animals and plants. In the Neopaleozoic, the dry lands increased in extent, and terrestrial plants and animals became abundant. Vertebrates increased greatly in number and variety, Amphibians making their appearance in the Devonian, and Reptiles in the Carboniferous era, in addition to the earlier class of Fishes. The Upper Silurian and Devonian are called the Age of Fishes, and the Carboniferous the Age of Amphibians, or the Age of Acrogens.

As has been already stated, and as will appear more clearly in the sequel, the American continent was essentially a unit in its evolution through all geological time. The areas of rock-making and geographical progress in the Paleozoic were accordingly defined by the conditions of Archæan geography. The map of North America at the close of the Archæan (Fig. 214) shows the shallow continental sea divided into three parts by the two great Archæan chains of islands or island ridges, following respectively the general course of the Appalachian and the Rocky Mountain chains. Those three regions — the *Interior Continental Sea*, the *Atlantic Border*, and the *Pacific Border* — require separate consideration in tracing the history of continental growth. The Atlantic Bor-

Crinoids, though the stem on which it stood is mostly wanting, and the arms are not entire. There were also true Starfishes in the seas.

Figs. 241-252.



Anthozoan: Fig. 241, Streptelasma corniculum. — Crinoid: Fig. 242, Taxocrinus elegans. — Bryozoans: Fig. 243, Stictopora acuta; 244, Prasopora lycoperdon; 245, section of same. — Brachiopods: Fig. 246, Orthis testudinaria; 247, Orthis occidentalis; 248, Leptæna sericea. — Mollusks: Fig. 249, Ambonychia bellistriata; 250, Rhaphistoma lenticulare; 251, Orthoceras junceum. — Trilobite: Fig. 252, Asaphus platycephalus, × ½.

Molluscoids. — Among Molluscoids, Bryozoans were very common. The fossils are small cellular corals: one is shown in Fig. 243.

A group of corals, mostly of small size, appearing in hemispherical (Fig. 244) or incrusting or branching forms, and consisting of minute columnar cells closely packed together (Fig. 245), were very abundant in the Lower Silurian. They were probably Bryozoans, though regarded by some paleontologists as true Anthozoan corals. One species is represented in Figs. 244, 245. Other important genera of the group are *Monticulipora*, *Chætetes*, etc.

Brachiopods were still more characteristic of the era, and occur in vast numbers. Three species are represented in Figs. 246–248.

Mollusks. — All the principal classes of Mollusks were represented. A Lamellibranch is shown in Fig. 249, and a Gastropod in Fig. 250. Shells of Cephalopods were especially common, under the form of a straight or curved horn with transverse partitions. Fig. 251 represents a small species. One species had a shell 12 or 15 feet long, and nearly a foot in diameter. The word *Orthoceras* is from the Greek ὀρθός, straight, and κέρας, horn. There were some species also of the genus *Nautilus*, a genus which has survived to the present time. While Trilobites appear to have been the largest and most powerful animals of the Cambrian seas, Cephalopods, of the *Orthoceras* family, far exceeded Trilobites in both respects in the Trenton. The larger kinds must have been powerful animals to have borne and wielded a shell 12 or 15 feet long. Although clumsy compared with the Fishes of a later age, they emulated the largest of Fishes in size, and no doubt also in their voracious habits.

Arthropods. — Fig. 252 represents one of the large Trilobites of the Trenton rocks, the *Asaphus platycephalus*, — a species sometimes found eight inches or more in length. Another genus of Trilobites, very common in the Lower Silurian, and represented also in the Upper Silurian, is *Calymene*, a species of which is shown in Fig. 116, page 77. The rocks of the Utica epoch, in a species became extinct. Scarcely any Cambrian species are known to occur in the Canadian period; very few of the species of the Canadian period survive into the Trenton; and very many of those of the early part of the Trenton did not exist in the later part. Thus life and death were in progress together, species being removed, and other species appearing, as time moved on.

Economic Products. — The Galena Limestone (Trenton period) of Wisconsin and the adjoining states derives its name from the deposits of lead ore which it contains. The ore occurs in cavities in the limestone, and its origin was probably much later than that of the rock.

A large amount of mineral oil and gas is afforded in some regions by the Trenton formation and chiefly the limestone. At Findlay, and some other places in Ohio, borings are made to a depth of several hundred feet, through the overlying rocks, and then for 10 to 50 feet into the limestone; the gas comes up with a rush, and continues to escape for years. From one boring over a million cubic feet of gas have been obtained per day. The gas is used both for illumination and for fuel. In other cases oil is obtained, which, when purified, becomes kerosene. The gas consists chiefly of marsh gas (CH_4), the principal ingredient of ordinary illuminating gas; and the oil consists of mixtures of other hydrocarbons. They were produced by the decomposition of the animal or vegetable substances in the rock, afforded by the life of the seas.

DISTURBANCES AT THE CLOSE OF THE LOWER SILURIAN.

Archæan time closed, as has been already remarked (page 240), with an epoch of general upturning and metamorphism, so that the Cambrian rocks are everywhere unconformable with the Archæan. But, from that time until the close of the Lower Silurian, no extensive dis-

GENERAL OBSERVATIONS.

Geography. — The wide continental region covered by the Trenton limestone formation, stretching over the Appalachian region on the east, and widely through the Interior basin, must have been throughout a clear sea, densely populated over its bottom with Brachiopods, Corals, Crinoids, Trilobites, and the other life of the era. It may, however, have been a shallow sea; for the corals and beautiful shells of coral reefs live mostly within 100 feet of the surface.

During the later part of the period, the Utica and Hudson epochs, the same seas, especially on the north, became more open to sediment, through some change of level or of coast barriers, and consequently much of the former life disappeared, and other kinds, adapted to impure waters or to muddy bottoms, supplied its place.

Life. — The appearance of the earliest land plants (Acrogens), the earliest Insects, and the earliest Fishes, marks the progress in life during the Lower Silurian.

Among the genera of the Lower Silurian, probably only seven have living species. These are *Saccammina* among Rhizopods, *Lingula*, *Discina*, *Rhynchonella*, and *Crania* among Brachiopods, *Avicula* among Lamellibranchs, and *Nautilus* among Cephalopods. *Discina* probably goes back even to the Cambrian, and perhaps *Lingula* also, though some systematists refer all the supposed Cambrian species to other genera. These genera of long lineage thus reach through all time from the Lower Silurian onward. All other genera disappear — some at the close of an era, others at the close of a period, epoch, or other subdivision of an era.

The extinction of species took place at intervals through the periods, as well as at their close; though the exterminations at the close of the periods were more general. With the changes from one stratum to another, there were disappearances of some species; and, with the changes from one formation to another, still larger numbers of out white or clouded marbles, now extensively quarried for architectural purposes at Canaan, Connecticut, in Berkshire County, Massachusetts, and at Rutland and elsewhere in Vermont.

The history of the Taconic range thus exemplifies the same stages already described with reference to the Appalachian range, which has been taken as a type of mountain structure: a slowly progressing geosyncline, in which a vast thickness of strata is accumulated; the weakening of the mass as the bottom of the trough becomes heated in its descent; and finally the crushing of the weakened strata to form the complex folds characteristic of a synclinorium. The Taconic range differs, however, from the Appalachian range, in that the rocks of the former have suffered a much more intense degree of metamorphism.

2. **The Taconic System.**— It is probable, also, that another mountain range was formed at the same time, commencing in the eastern part of Canaan, Connecticut, and continuing southward through Westchester County, New York, to Manhattan Island; and still another, if not a continuation of the last, extending from the vicinity of Philadelphia to Buckingham County, Virginia (where the crystalline rocks have afforded fossils), and beyond this southwestward. These ranges extending southward and southwestward beyond the Taconic range proper have suffered so much denudation as no longer to constitute strongly marked geographical features, though the orogenic movements are indicated by the disturbed and metamorphosed rocks. The Taconic revolution, in this view, left its marks in mountains and in crystalline rocks along the whole Atlantic Border, and the two or three mountain ranges dating from that time constitute together a long Taconic mountain system.

3. **Emergence of the Atlantic Border Region.** — Simultaneously with the formation of the Taconic system, a large part of the Appalachian Border region was raised above the sea level. This is proved by the fact that, along

disturbances occurred either in eastern North America or in Europe. The alternations of limestones with shales and sandstones during the Eopaleozoic are evidence, indeed, that changes of level, by gentle movements or oscillations of the earth's crust, were going on. But the close of Eopaleozoic time was signalized by geographical changes of a much more striking character.

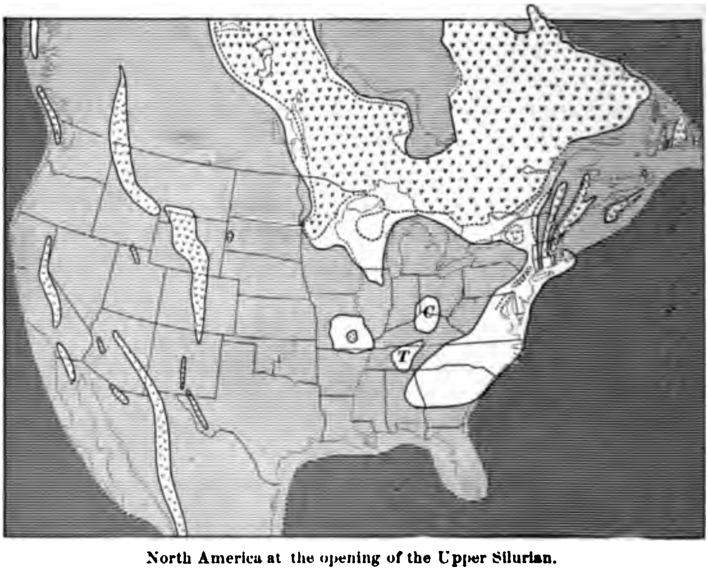
1. **The Taconic Range.** — This mountain range, 500 miles long, extending along the western and northwestern border of New England, from Canada to northwestern Connecticut and Putnam County in eastern New York, was made at the close of the Lower Silurian. That the region was not dry land before, is shown by the presence of Chazy and Trenton Limestones, for these are of marine origin: and that the region was above the water from and after this time, is indicated by the fact that the formations of the Trenton period were the latest there formed; and by the still more important observation that, near Hudson, in the Hudson River valley, and at other localities, near the border of the Taconic region, there are Upper Silurian rocks overlying unconformably the upturned older rocks, the uplift being shown thereby to have preceded the deposit of the Upper Silurian rocks.

During the progress of the Lower Silurian era a great thickness of rock had been made over the region of the Taconic Mountains, — probably 15,000 or 20,000 feet. These beds were laid down, not in a sea 15,000 or 20,000 feet deep until it was full, but in shallow waters over a bottom that was gradually sinking — so gradually that the rock material accumulating over it kept it shallow. Then, when the slowly forming trough had reached this depth, the epoch of catastrophe, that is, of mountain-making, began, when the beds were displaced and folded, and consolidated or crystallized. Quartzose sandstones were changed to hard quartzite — the rock of high ridges in Berkshire and Vermont; earthy sandstones were made into mica schist and gneiss; and common limestones came

GEOGRAPHICAL CONDITIONS AT THE OPENING OF THE ERA.

The accompanying map shows approximately the areas where Archæan and Eopaleozoic rocks are surface rocks, and which were therefore probably, for the most part, dry land at the beginning of the Upper Silurian. There may have been, however, other areas which were dry land at that time, but which have been subsequently

Fig. 255.



North America at the opening of the Upper Silurian.

covered by newer formations. The portion of those areas where Archæan rocks are surface rocks is indicated by a shading composed of V's, except that, in the Atlantic Border region, the Archæan rocks have not been fully distinguished from metamorphic rocks of later date, and no attempt is therefore made to indicate their boundaries on the map.

A comparison of this map with that on page 237 will show that the area of dry land was not greatly increased during the Eopaleozoic. The Atlantic Border region, south of New York, had become dry land, and was no longer receiving deposits. The marine connection which had existed between the Interior Continental sea and the Atlantic, through the St. Lawrence channel, was closed by the elevation of land in the region of Lake Champlain. It is, however, probable that communication between the Interior Continental sea and the Gulf of St. Lawrence was temporarily reopened in the closing period of the Upper Silurian. The Gulf of St. Lawrence extended southward in long bays in the troughs between the eastern ridges of Archæan rocks, and in these bays Upper Silurian rocks were deposited. The separation between the Interior Continental sea and the Gulf of St. Lawrence, and the free opening of the former into the Pacific, had a marked effect on the marine faunas of the different regions. The fossils of Canada and New England show the influence of migration from western Europe; while the Interior Continental sea was open to immigration from the old world chiefly by way of the Pacific. An Eastern Interior sea or bay was imperfectly separated from the main body of the Interior Continental sea by the line of islands and shallows formed by the Cincinnati uplift; and it was in the eastern part of this bay that the vast subsidence of the Appalachian geosyncline was in progress.

SUBDIVISIONS.

The Upper Silurian era in North America includes three periods: — 1, NIAGARA; 2, ONONDAGA; 3, LOWER HELDERBERG.

The name of the first is from the Niagara River, along which the rocks are displayed; that of the second, from the name of a town and county in central New York; that of the third, from the Helderberg Mountains, south of Albany, where the lower rocks are of this period.

ROCKS: KINDS AND DISTRIBUTION.

1. **Niagara Period.** — The rocks of the Niagara period, in the eastern part of the Interior Continental region of North America, are: — (1) A conglomerate and grit rock called the Oneida Conglomerate, which extends from central New York southward along the Appalachian region, having a thickness of 700 feet in some parts of Pennsylvania; which, together with the Medina Sandstone, spreading westward from central New York through Michigan, and also southward along the Appalachian region, being 1500 feet thick in Pennsylvania, is included in the *Medina* epoch; (2) Hard sandstones, or flags and shales, with some limestones (particularly westward) and some beds of iron ore, belonging to the *Clinton* epoch, having nearly the same distribution as the Medina formation, though a little more widely spread in the west, and about 2000 feet thick in Pennsylvania; (3) The formations of the *Niagara* epoch, occurring in New York from the Hudson to the Niagara, and extending widely over the Interior Continental region; they consist, at Niagara, of shale below and thick limestone above, but mainly of limestone in the Interior region. The Niagara is one of the great limestone formations of the continent, existing also in the Arctic regions.

Ripple-marks and mud-cracks are very common in the Medina formation. The example of rill-marks figured on page 155 is from its strata in western New York.

The section, Fig. 256, represents the rocks on the Niagara River at and below the Falls. The Falls are at F; the Whirlpool, three miles below, at W; and the Lewiston Heights, which front Lake Ontario, at L. Nos. 1, 2, 3, 4 are different sandstone and shale strata of the Medina epoch; 5, shale, and 6, limestone, of the Clinton epoch; 7, shale, and 8, limestone, of the Niagara epoch.

2. **Onondaga Period.** — The rocks of the Onondaga period include the Salina beds and the Water-lime group.

The Salina beds are fragile, clayey sandstones and shales, usually reddish in color, and including a little limestone. They occur in New York, in western Ontario, and in the vicinity of Cleveland, Ohio.

The salt of Salina and Syracuse, in central New York, is obtained from wells of salt water 150 feet and upward in depth, which are borings into these saliferous rocks. From 35 to 45 gallons of the water afford a bushel of salt, while of sea water it takes 350 gallons for the same amount. No solid salt is there found; but farther south and west one or more beds of rock salt occur over an area measuring 150 miles from east to west and probably not less than 60 miles from north to south. The aggregate thickness of these salt beds varies widely, being, in the vicinity of Ithaca, about 250 feet, though much less than that in most places. At Ithaca, the total thickness of the Salina formation is 1230 feet, and it is covered by 1900 feet of later strata. Beds of rock salt are also found at Goderich, Ontario, and near Cleveland.

The rocks of the Water-lime group are impure magnesian limestones. Owing to these impurities, the quicklime made from the rock will set under water, and is accordingly used in the manufacture of hydraulic cement. The name of the group refers to that fact.

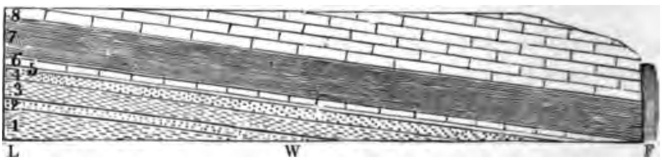
Both the Salina and the Water-lime beds contain gypsum, sometimes in layers, sometimes in imbedded masses. In some cases it may have been formed directly, like the salt, by the evaporation of sea water. But much of it has resulted from the decomposition of the limestone by the action of sulphuric acid derived from the oxidation of the sulphuretted hydrogen dissolved in subterranean waters. Sulphur springs are common in the region.

3. **Lower Helderberg Period.** — The Lower Helderberg group consists mainly of limestones, and is the second limestone formation of the Upper Silurian. The formation is well developed in the State of New York and along the Appalachian region to the south. It also

occurs in Tennessee and probably in southern Illinois; but the beds are thin or wanting over most of the Central Interior region. The formation is also found in Canada in the line of the Connecticut Valley, in northern Maine, and in New Brunswick and Nova Scotia.

Upper Silurian Rocks in Europe. — In Great Britain the base of the Upper Silurian rocks is formed by conglomerates, sandstones, and shales, called, where occurring in South Wales, the Llandovery group, and corresponding

Fig. 256.



Section along the Niagara, from the Falls to Lewiston Heights.

to the Medina and Clinton groups. Above these there is the Wenlock group, consisting of limestone and some shale (including, in the upper portion, the Dudley Limestone), and corresponding to the Niagara group. These rocks occur as surface rocks near the borders of Wales and England. Next comes the Ludlow group, of the age of the Onondaga and Lower Helderberg beds.

LIFE.

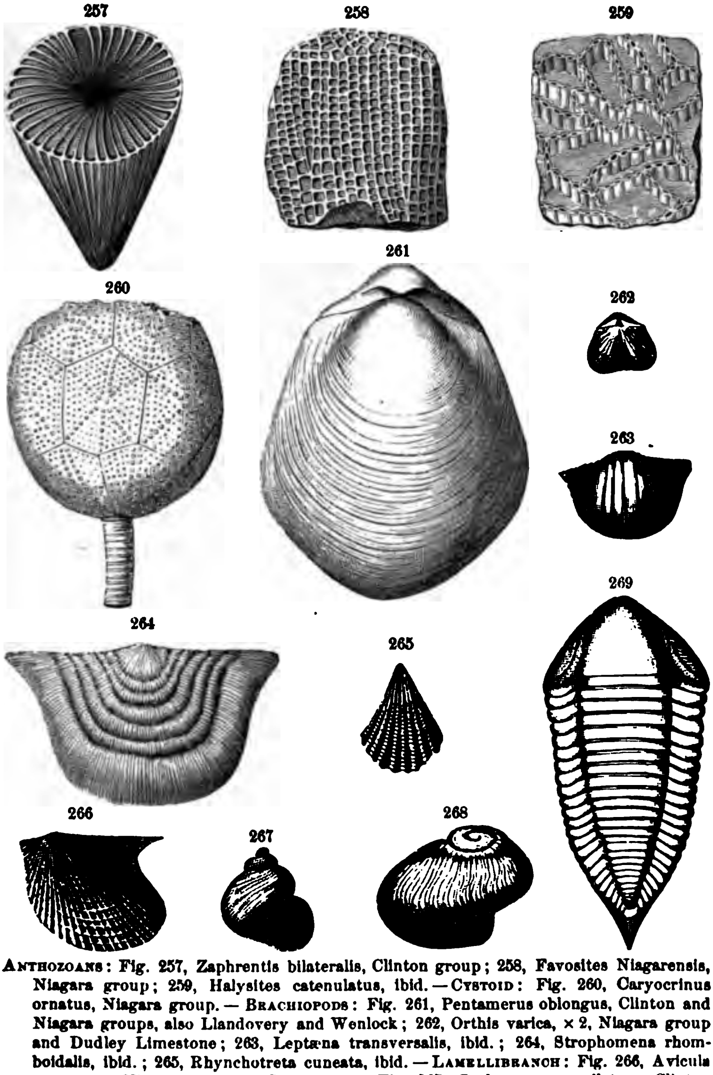
The limestone strata and most of the other beds of the Niagara group are full of fossils; and so also are the rocks of the Lower Helderberg period, and of the Wenlock and Ludlow formations in Great Britain. Fossils are well-nigh wanting in the Salina beds, and not abundant in the Waterlime.

The life of the era was the same in general features as that of the latter part of the Lower Silurian, though mostly different in species.

The most of the vegetable remains are those of Seaweeds; but the Lower Helderberg rocks of this country

[redacted]

Figs. 257–269.



Anthozoans: Fig. 257, Zaphrentis bilateralis, Clinton group; 258, Favosites Niagarensis, Niagara group; 259, Halysites catenulatus, ibid. — **Cystoid**: Fig. 260, Caryocrinus ornatus, Niagara group. — **Brachiopods**: Fig. 261, Pentamerus oblongus, Clinton and Niagara groups, also Llandovery and Wenlock; 262, Orthis varica, × 2, Niagara group and Dudley Limestone; 263, Leptæna transversalis, ibid.; 264, Strophomena rhomboidalis, ibid.; 265, Rhynchotreta cuneata, ibid. — **Lamellibranch**: Fig. 266, Avicula emacerata, Niagara group. — **Gastropods**: Fig. 267, Cyclonema cancellatum, Clinton group; 268, Platyceras angulatum, Niagara group. — **Trilobite**: Fig. 269, Homalonotus delphinocephalus, × ½, Niagara group.

have afforded a few remains of Acrogens, representing apparently both the Equiseta and the Lycopods.

Among animals, the Cœlenterates were represented chiefly by Anthozoan corals, the Echinoderms by Crinoids, and the Molluscoids by Brachiopods. The last are especially abundant, their shells outnumbering all other fossils. All the principal classes of Mollusks were represented, Cephalopods of the *Orthoceras* group being most characteristic. Arthropods were represented by Trilobites, Ostracoids, and Leptostracans, among Crustaceans, also by Merostomes, Arachnoids, and Insects. The only Vertebrates were Fishes.

Cœlenterates. — Fig. 257 is a coral of the Cyathophylloid group, showing the radiating plates of the interior; Fig. 258, a species of *Favosites*, a genus in which the cells have a columnar form (somewhat honeycomb-like, whence the name, from Latin *favus*, honeycomb), and are divided by transverse partitions; Fig. 259, a Chain Coral, *Halysites* (Greek ἅλυσις, chain), the cells appearing, in a transverse section, like links of a chain.

Echinoderms. — Fig. 260 is a Cystoid with the arms broken off. Another Cystoid of the Niagara group is shown in Fig. 82, on page 67. A Starfish, also of the Niagara, is shown in Fig. 86, on page 68.

Molluscoids. — Figs. 261–265 are Brachiopods of the Niagara period; Figs. 270–274, Brachiopods of the Lower Helderberg.

Mollusks. — Fig. 266 is a Lamellibranch, and Figs. 267, 268, Gastropods, of the Niagara period.

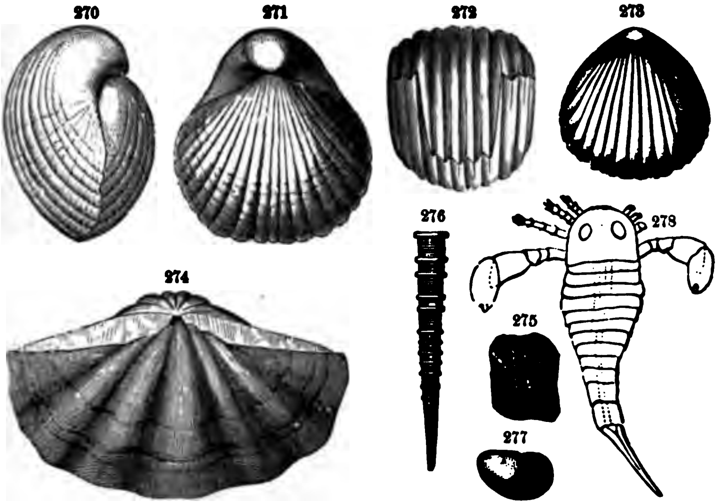
Fig. 275 represents small, slender, tubular cones, called *Tentaculites*, which almost make up the mass of some layers in the Water-lime group; the form of one enlarged is shown in Fig. 276; they are regarded as shells of Pteropods. The same genus is abundant also in the Lower Helderberg.

Arthropods. — Fig. 269 is a reduced figure of a common Trilobite of the Niagara group. The species is often 8 or 10 inches in length.

Fig. 277 is an Ostracoid Crustacean, *Leperditia alta*, of unusually large size for that group, modern Ostracoids seldom exceeding a twelfth of an inch in length.

Fig. 278 is a *Eurypterus*, a representative of the class of Merostomes, of which the *Limulus*, or Horseshoe Crab, is now the sole surviving genus. The *Eurypterus* group makes its first appearance in the Utica Shale, but is more characteristic of Neopaleozoic time, attaining its greatest

Figs. 270–278.



Brachiopods: Figs. 270, 271, Pentamerus galeatus; 272, 273, Rhynchonella ventricosa; 274, Spirifer macropleurus. — Pteropod: Fig. 275, Tentaculites gyracanthus; 276, same, enlarged. — Ostracoid: Fig. 277, Leperditia alta. — Merostome: Fig. 278, Eurypterus remipes, a small specimen. Figs. 270–274 are species from the Lower Helderberg; Figs. 275–278, from the Water-lime.

development in the Upper Silurian. The species figured is from the Water-lime, and is sometimes nearly a foot long. Species of the same order occur in Great Britain in the Wenlock and Ludlow beds, and one of them is supposed, from the fragments found, to have been 6 or 8 feet long, far surpassing any Arthropod now living. The Upper Silurian of Great Britain has also afforded forms still more closely related to the modern *Limulus*.

Arachnoids are represented by Scorpions, which have been found in the Water-lime group in New York, and also in the Upper Silurian of Scotland and Sweden.

Vertebrates. — Remains of Fishes have been found in the Clinton and the Water-lime of this country, and in the Ludlow beds of Great Britain. They include plates of Placoderms, and probably fin spines of Selachians.

GENERAL OBSERVATIONS.

On the map, page 235, the areas over which the Cambrian and Silurian formations are surface rocks are distinguished by being horizontally lined. It is observed that they spread southward from the northern Archæan area, and indicate an extension of the growing continent in that direction.

South of the Silurian area commences the Devonian, which is vertically lined; and the limit between them shows approximately the course of the seashore at the close of the Upper Silurian era. It is seen that more than half of New York, and nearly all of Canada and Wisconsin, had by that time become part of the dry land; but a broad bay covered the Michigan region to the northern point of Lake Michigan, for here Devonian rocks, and to some extent Carboniferous, were afterward formed. The Archæan dry land, the nucleus of the continent, had also received additions in a similar manner on its eastern and western sides, through British America. And there may have been other areas of dry land which were subsequently submerged and covered by more recent strata.

But, with all the increase, the amount of dry land in North America was still small. Europe is proved by similar evidence to have had much submerged land. The surface of the earth was a surface of great waters, with the continents only in embryo — one large area and some islands representing that of North America, and an archipelago that of Europe. The emerged land, moreover, was most extensive in the higher latitudes. The rivers

Upper Silurian along the Appalachian region leads to many interesting conclusions. The Appalachian region was in strong contrast with the Central Interior region, where the series of contemporaneous beds is hardly one tenth as thick. Taking this into connection with another fact, that very many of the strata among the thousands of feet of Upper Silurian formations in the Appalachian region contain those evidences of shallow-water and mud-flat or sand-flat origin above explained, there is full proof that, in the Upper Silurian era, the region was for the most part a shallow sea border receiving the debris from the Atlantic Border region, which had emerged as a land area at the close of the Lower Silurian. The great thickness of the strata was rendered possible by the progressive subsidence which was preparing the Appalachian region for the mountain-making epoch at the close of Paleozoic time.

During the Cambrian and Lower Silurian eras a similar gradual subsidence had permitted the accumulation of the thick series of strata which were upturned and metamorphosed in the making of the Taconic Mountains. The subsiding area during the Upper Silurian era extended from Pennsylvania northward into New York, and not along the Taconic region; the rocks in the state of New York have great thickness for some distance beyond the Pennsylvania border.

II. DEVONIAN ERA.

SUBDIVISIONS.

The Devonian formation was so named by Sedgwick and Murchison, from Devonshire, England, where it occurs.

The era may be divided into four periods: — 1, ORISKANY; 2, CORNIFEROUS; 3, HAMILTON; 4, CHEMUNG. The Oriskany and Corniferous periods are often called Lower Devonian; the Hamilton, Middle Devonian; and the Chemung, Upper Devonian.

ROCKS: KINDS AND DISTRIBUTION.

1. **Oriskany Period.** — The Oriskany beds are mostly rough calcareous sandstones. The formation extends from Oriskany, New York, southward along the Appalachian region through Pennsylvania, Maryland, and Virginia, where it is several hundred feet thick. It occurs also in northern Maine, and at Gaspé on the Gulf of St. Lawrence, where the rock is partly limestone.

2. **Corniferous Period.** — The lowest rocks of this period are fragmental beds, called the *Cauda-Galli Grit* and the *Schoharie Grit*, having their distribution along the Appalachian region, commencing in central and eastern New York, and extending southwestward into Pennsylvania.

Next follows the great *Corniferous Limestone*, the lower part of which is sometimes called the Onondaga Limestone, and the whole of which is often called the Upper Helderberg group. It stretches from eastern New York westward to the states beyond the Mississippi.

The name *Corniferous* (derived from the Latin *cornu*, horn) was given it by Eaton, from its frequently containing a variety of quartz called hornstone. This hornstone differs from true flint in being less tough, or more splintery in fracture, though it is like it in hardness and in consisting of silica.

The limestone is in many places literally an ancient coral reef. It contains corals in vast numbers and of great variety; and in some places, as at the Falls of the Ohio, near Louisville, Kentucky, the resemblance to a modern reef is perfect. Some of the coral masses at that place are 5 or 6 feet in diameter; and single polyps of the Cyathophylloid corals had in some species a diameter of 2 or 3 inches, and in one species a diameter of 6 or 7 inches.

The same reef rock occurs near Lake Memphremagog on the borders of Vermont and Canada, and also at Little-in New Hampshire; but the corals have in these places been partly obliterated by metamorphism.

The Corniferous Limestone in some places abounds in mineral oil. The oil wells of Enniskillen, Ontario, are from this rock.

3. **Hamilton Period.** — The Hamilton formation consists in New York of sandstones and shales, with a few thin layers of limestone. It consists of two parts corresponding to two epochs: the lower part is called the *Marcellus Shale;* the upper, the *Hamilton beds.* It has its greatest thickness along the Appalachians. From New York it spreads westward, where it is in part calcareous. The formation occurs also in New Brunswick, and at Gaspé, on the Gulf of St. Lawrence.

The Hamilton beds afford an excellent flagging stone in central New York, and on the Hudson River, near Kingston, Saugerties, Coxsackie, and elsewhere, which is extensively quarried and exported to other states.

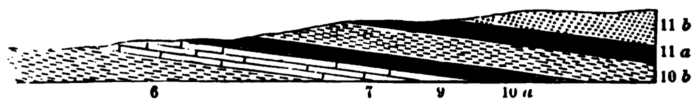
4. **Chemung Period.** — The Chemung period includes two epochs, the *Portage*, and the *Chemung* proper. The Portage beds are mainly shales and shaly sandstones; the Chemung beds mainly sandstones, or shaly sandstones, with some conglomerate. The base of the Portage is formed by a stratum of black bituminous shale called the Genesee Shale. The beds of the Chemung period spread over a large part of southern and western New York, attaining a thickness of between 2000 and 3000 feet.

In the following section, taken on a north-and-south line south of Lake Ontario, No. 6 represents the beds of the Onondaga period; 7, the Lower Helderberg Limestone; 9, the Corniferous, or Upper Helderberg, Limestone; 10 *a*, *b*, the Hamilton beds; 11 *a*, the Genesee Shale; and 11 *b*, the overlying beds of the Chemung group.

In the Catskill Mountains, the Portage and Chemung epochs are not distinguished from each other, being jointly represented by a mass of sandstones, varying into conglomerates and shales, predominantly red, called the Catskill group. The rocks in the Catskills have a thickness of 3000 feet. The same formation extends southwestward along the Appalachians into Pennsylvania, attaining near Mauch Chunk a thickness of more than 7500 feet.

The Upper Devonian, like most of the Paleozoic formations, is much thinner in the Central Interior region than along the Appalachians. It is chiefly represented in the Central Interior by a bituminous shale resembling the

FIG. 279.



Section of Upper Silurian and Devonian formations south of Lake Ontario.

Genesee Shale of New York, and commonly called the "Black Shale." In Ohio, the Upper Devonian is represented by the Huron, Erie, and Cleveland Shales.

The Upper Devonian is the great "oil horizon" of Pennsylvania.

Devonian Rocks in Europe. — In Great Britain the Devonian rocks include the Old Red Sandstone, the prevailing rock of the age in Wales and Scotland; and slates and limestones in Devon and Cornwall. The thickness of the Old Red Sandstone in some places in Scotland is said to be 10,000 to 16,000 feet. The Devon beds are estimated to be 10,000 to 12,000 feet in thickness. The distribution in Great Britain is shown on the map, page 295. In Germany, in the Rhenish provinces, there is a coral limestone very similar to that of North America.

LIFE.

General Characteristics.

The Devonian was characterized by forests and an abundance of Insects over the land, and by Fishes of many kinds in the waters. The earliest Amphibians probably appeared in this era.

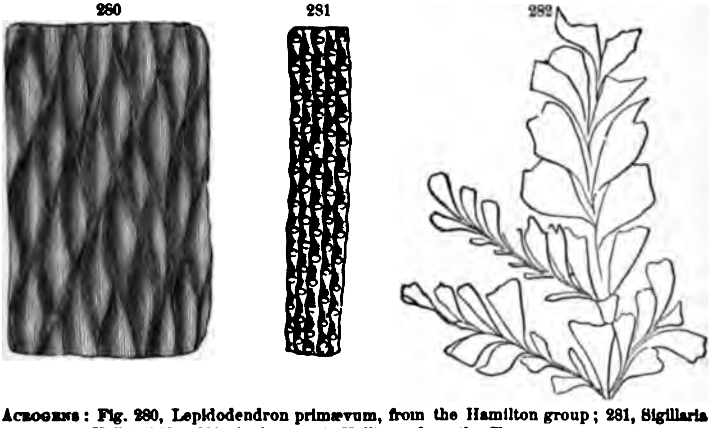
Plants.

Cryptogams. — The hornstone of the Corniferous and other limestones develops, under the microscope, the fact that it was probably made from the siliceous remains of plants and animals, — shells of Diatoms, spicules of Sponges, and other organic relics having been detected in it.

Figs. 280–282 represent portions of some of the land plants. Fig. 282 is a fragment of a Fern, and Figs. 280,

Figs. 280–282.

280 281 282



Acrogens: Fig. 280, Lepidodendron primævum, from the Hamilton group; 281, Sigillaria Hallii, ibid.; 282, Archæopteris Halliana, from the Chemung group.

281, are portions of Lycopodiaceous trees. The scars or prominences over the surface are the points of attachment of the fallen leaves; a dried branch of a Norway Spruce, stripped of its leaves, looks somewhat like Fig. 281. By referring to page 88, it will there be seen that among the Flowerless Plants or Cryptogams there is one group, the highest, that of Acrogens, in which the plants have upward growth like ordinary trees, and the tissues are partly vascular: it is the one containing the Ferns, Lycopods, and Equiseta or Horsetails. The most of the land plants of the Devonian belong to the three orders just mentioned.

A somewhat fuller description of these groups is here appropriate, since in the Devonian era, for the first time, they attained such development as to clothe the land with forests.

1. *Ferns.* — The species have a general resemblance to the Ferns or Brakes of the present time.

2. *Lycopods.* — These are plants related to the Ground Pine. The existing plants of this tribe are slender species, seldom more than a few inches in height, though the creeping stems of some species may be many feet in length. Some of the ancient species were of the size of forest trees. These ancient species belong mostly to two groups, of which the genera *Lepidodendron* and *Sigillaria*, respectively, are the types. In the former, the scars are contiguous, and are arranged in quincunx order, that is, alternate in adjoining rows, as shown in Fig. 280. The name *Lepidodendron* is from the Greek λεπίς, scale, and δένδρον, tree, and alludes to the scar-covered trunk, which looks somewhat like a scale-covered reptile. The Sigillarids include trees of moderate height, with stout, sparingly branched trunks, bearing long, linear leaves much like those of the Lepidodendrids; but the scars on the exterior are in parallel vertical lines, as in Fig. 281, and Fig. 308, page 300. The name is from the Latin *sigillum*, seal, in allusion to the scars.

3. *Equiseta*, or *Horsetails.* — The Equiseta of modern wet woods are slender, hollow, jointed rushes, called sometimes Scouring Rushes. They often have a circle of slender leaflike appendages at each joint. The Calamites or Tree Rushes, which are referred to this group, are peculiar to the ancient world, none having existed since the Paleozoic. They had jointed stems like the Equiseta, and otherwise resembled them. But they were often a score of feet or more in height, and over 6 inches in diameter. Fig. 311, page 300, represents a portion of one of these plants.

Phanerogams. — Others of the land plants belong to the lowest class of Flowering Plants or Phanerogams, called Gymnosperms (see page 90).

Both of the principal orders of Gymnosperms — the Conifers and the Cycads — seem to be represented in the Devonian. Some of the Paleozoic genera appear to be in some respects intermediate between the two orders, and there is some doubt to which they should be referred. The fossils are impressions of leaves and portions of the trunk or branches.

Animals.

The early Devonian was the coral period of the ancient world. In no age before or since have coral reefs of greater extent been formed.

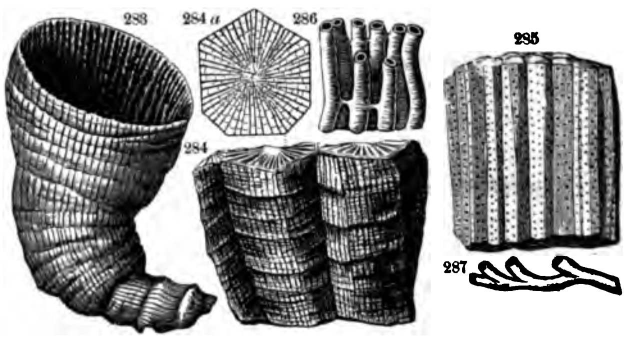
The Molluscoid Brachiopods still predominated over the Mollusks, though Lamellibranchs and Gastropods were more abundant than in the Silurian. A new type of Cephalopods commenced in the Lower Devonian. Hitherto, the partitions or septa in the shells, straight or coiled, were flat or simply concave; but in the new genus *Goniatites* the margin of the septum is crumpled into one or more deep flexures. The name is from the Greek *γωνία*, angle. Fig. 293 (page 283) represents one of the species, and Fig. 293 *a* shows some of the flexures along the margin of the shell.

Trilobites continued to be the dominant group of Crustaceans, though less abundant than in the Silurian. The earliest of the order of Decapods (the order now represented by Lobsters, Crabs, etc.) appeared in the Devonian era. The earliest species were Macrurans, the higher group of Brachyurans (Crabs) appearing much later. Land Arthropods were represented by Insects and Myriopods; the wings of some species of Insects having been reported from the Devonian of New Brunswick, and two species of Myriopods having been described from the Old Red Sandstone of Scotland.

The increase of Fishes in number of species and diversity of types forms the most marked characteristic of the era. The appearance of Amphibians is an important step of progress.

Cœlenterates. — Figs. 283, 284, are two species of Cyathophylloid corals from the Corniferous. Both are found at the Falls of the Ohio, where the latter species, *Cyathophyllum rugosum*, forms very large masses. Fig. 285 is a species of *Favosites* from the same locality, occurring also in Europe. Figs. 286, 287, are small corals, probably belonging to the group of Alcyoniarians.

FIGS. 283–287.



ANTHOZOANS: Fig. 283, Zaphrentis Rafinesquii; 284, 284 *a*, Cyathophyllum rugosum; 285, Favosites Goldfussi; 286, Syringopora Maclurii; 287, Romingeria cornuta. All from the Corniferous period.

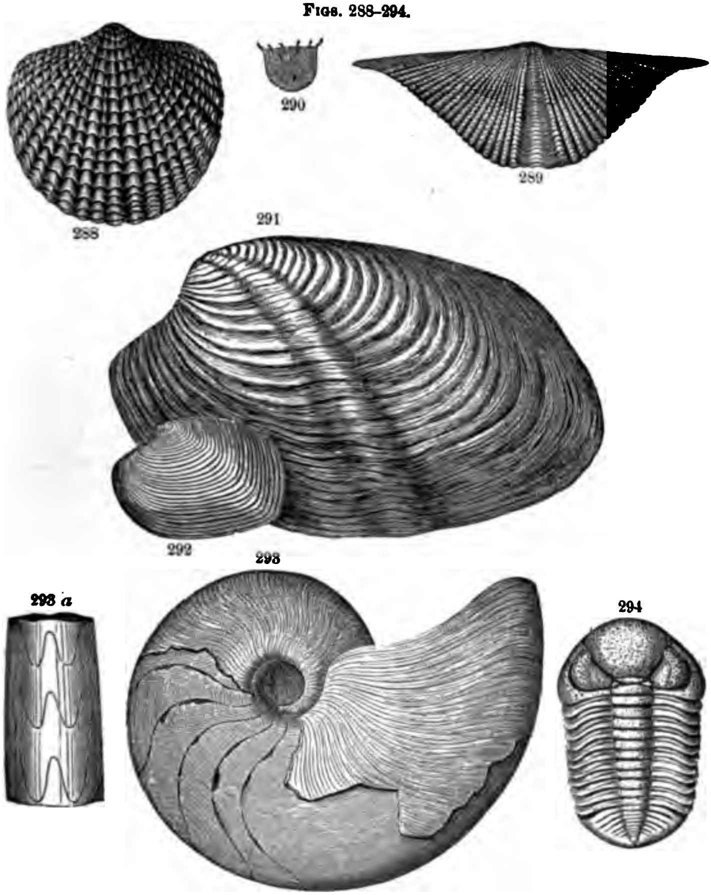
Molluscoids. — Figs. 288–290 are Brachiopods of the Hamilton period.

Mollusks.— Figs. 291, 292, are Hamilton Lamellibranchs. Fig. 293 is a Cephalopod, a species of *Goniatites*, from the same formation. Fig. 293 *a* is a view of a part of the margin of the shell, showing the crumpled edges of the septa.

Arthropods. — Fig. 294 is one of the most common species of Trilobites of the Hamilton. Remains of Insects have been found in beds supposed to be of the Hamilton period, at St. John, New Brunswick. A wing of a gigantic species of May-fly is represented in Fig. 295.

The earliest Myriopods thus far discovered are from the Old Red Sandstone of Scotland.

FIGS. 288–294.



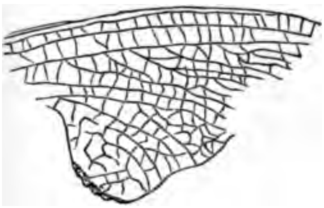
BRACHIOPODS: Fig. 288, Atrypa aspera; 289, Spirifer pennatus; 290, Chonetes setigerus. — LAMELLIBRANCHS: Fig. 291, Grammysia bisulcata; 292, Microdon bellistriatus. — CEPHALOPOD: Figs. 293, 293 *a*, Goniatites Vanuxemi. — TRILOBITE: Fig. 294, Phacops rana. All from Hamilton group.

Vertebrates. — The Fishes of the Devonian belong to four subclasses: — 1, *Selachians;* 2, *Placoderms;* 3, *Gan-*

oids; 4, *Dipnoans*. These groups have been defined on pages 81–84.

The *Selachians*, or Sharks, belong, for the most part, to the family of Cestracionts, in which the mouth has a pavement of broad, flat-crowned teeth for grinding, as shown in Figs. 129–131, on page 82. There were species as large as the largest of modern time. Fig. 296 represents a fin spine of a shark, two thirds its actual size, from the Corniferous beds of New York.

Fig. 295.



Insect: wing of Platephemera antiqua.

The *Placoderms* are an extremely aberrant group, known exclusively as Silurian and Devonian fossils. Some of them are represented in Figs. 297–300. Figs. 297–299 are Fishes from the Old Red Sandstone of Great Britain. Fig. 300 is a gigantic Placoderm from Ohio, named by Newberry *Dinichthys* (Greek δεινός, terrible, ἰχθύς, fish), which had a head four feet wide.

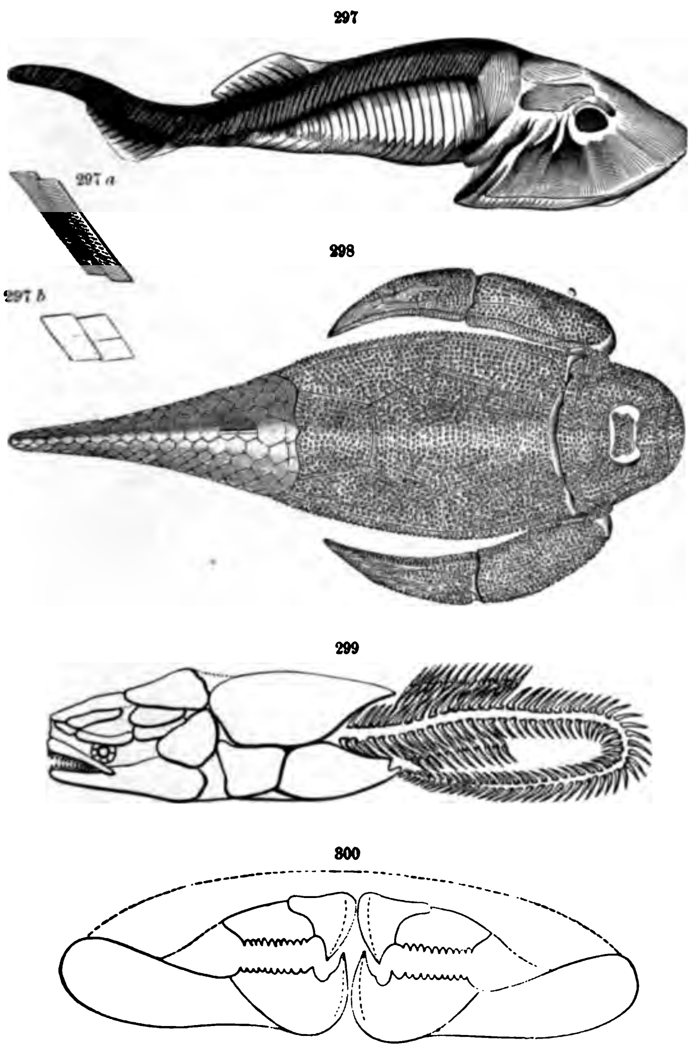
Fig. 296.

Selachian: fin spine of Machæracanthus sulcatus, $\times \frac{2}{3}$.

As the Placoderms are known only in fossil condition, their true nature is somewhat problematical. Some of them, as *Cephalaspis* and *Pterichthys* (Figs. 297, 298), appear to have had no lower jaw (at least, none capable of fossilization). It is doubtful whether they were truly Fishes. Others, as *Coccosteus* and the gigantic *Dinichthys* (Figs. 299, 300), had well-developed jaws, and are believed by many paleontologists to have been an aberrant group of Dipnoans.

One of the *Ganoids* is shown in Fig. 301. The Ganoids

Figs. 297–300.

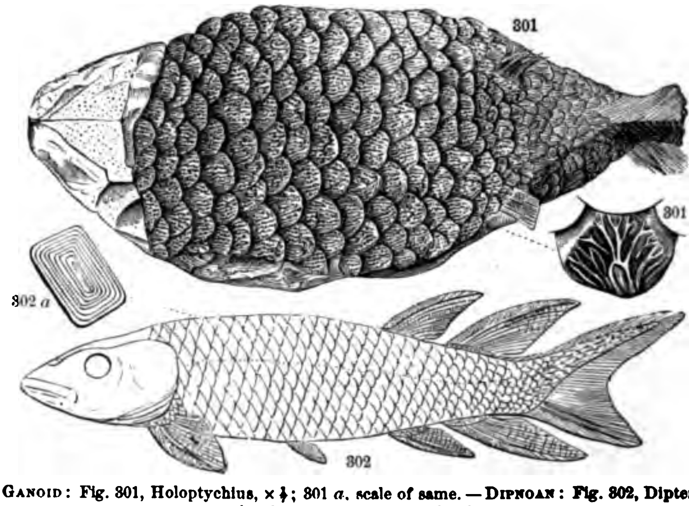


Placoderms: Fig. 297, Cephalaspis Lyelli, × $\frac{2}{3}$; 297 *a*, *b*, scales of same; 298, Pterichthys Milleri, × $\frac{2}{3}$; 299, Coccosteus decipiens, × $\frac{1}{4}$; 300, Dinichthys Hertzeri, front view of jaws, × $\frac{1}{15}$.

are now represented by only a few species, among which is the Gar Pike of North American lakes and rivers.

The *Dipnoans* are in many respects similar to the Ganoids, but they show a close relation to the Amphibians in the structure of the heart and of the skull. They are at present even less numerous than the Ganoids. One of the Devonian Dipnoans is represented in Fig. 302. The figure shows the vertebrated (heterocercal) tail. A vertebrated tail (heterocercal or diphycercal) was

FIGS. 301, 302.



GANOID: Fig. 301, Holoptychius, × $\frac{1}{4}$; 301 *a*, scale of same. — DIPNOAN: Fig. 302, Dipterus macrolepidotus, × $\frac{1}{2}$; 302 *a*, scale of same.

generally characteristic of Paleozoic Fishes, whether Selachians, Ganoids, or Dipnoans. The vertebrated character of the tail has been retained by Selachians and Dipnoans to the present time; but most of the Ganoids after the Paleozoic have the tail homocercal.

An impression supposed to be the track of an *Amphibian* was found in 1896, in the Upper Devonian rocks of western Pennsylvania. This is the most ancient representative yet discovered of the classes of Vertebrates above Fishes.

GENERAL OBSERVATIONS.

Geography. — During the Silurian, there had been a gradual gain of dry land, extending the Archæan continent southward (page 272). This gain continued through the Devonian, so that the formations of the next era, the Carboniferous, extend only a short distance north

FIG. 308.

Map of part of North America at the commencement of the Carboniferous era.

of the southern boundary of New York. The seashore was thus being set farther and farther southward with the successive periods. The Cincinnati Island became connected with the mainland, becoming the extremity of a peninsula extending southeastward from northern Illinois. The Eastern Interior sea thus acquired more distinctly the character of a bay. The Tennessee Island became submerged. The map, Fig. 303, illustrates the geographical progress during the Devonian.

The formations have their greatest thickness along the Appalachian region, in the Devonian era, as in the Silurian. And both this fact and the succession of different kinds of strata lead to the general conclusions stated on page 275. The Devonian age passed quietly for the larger part of the North American continent, without any tilting of the rocks; yet not without wide, though small, changes of level, varying the limits and depth of the Interior sea, such changes of level and of limits being indicated by the varying limits of the rocks, all of which are of marine origin. This quiet was not interrupted between the Devonian and Carboniferous eras, so far as yet discovered, except to the northeast in the region of New Brunswick, Nova Scotia, and northeastern Maine. There an upturning and flexing of the beds occurred, and, as a result, some mountain-making.

In Europe, also, the Devonian and Carboniferous strata are conformable, with only slight local exceptions.

Life. — The great features of the Devonian age are the occurrence of forests of Acrogens and Gymnosperms; the increasing number of Insects and the first appearance of Myriopods, among terrestrial Arthropods; and the great abundance and variety of Fishes, and the first appearance of Amphibians.

That Acrogens should have appeared in the Silurian and Devonian, while no traces have been found of the more lowly organized terrestrial plants, which, according to the theory of evolution, might have been expected to precede the Acrogens, will not appear strange when it is remembered that the Acrogens are the lowest plants which contain wood in their tissues. A Seaweed, in spite of the perishable nature of its tissues, may readily be preserved as a fossil, since the station in which it lives affords the opportunity for it to be buried before it has time to decompose. But a woodless terrestrial plant can be preserved as a fossil only by a very exceptional combination of circumstances.

That Gymnosperms should have been the earliest of Phanerogams is of course precisely what would be expected. The step of progress from Acrogens to Gymnosperms is a short one.

The fact that Vertebrates should have commenced in the Silurian and Devonian with somewhat highly organized forms, is a case somewhat analogous with that of the Acrogens. According to the theory of evolution, the primitive Vertebrates should have been creatures allied to the Leptocardians. But Leptocardians (as represented by *Amphioxus*) have neither bones, teeth, scales, nor fin spines — nothing, in fact, capable, under any ordinary conditions, of being preserved in fossil condition. The class of Marsipobranchs seems not much better fitted for fossilization, though the living members of the class do have little teeth implanted in the mucous membrane of the mouth, which might be preserved in scattered condition. When a Vertebrate has acquired sufficient skeletal development to have a good chance of preservation, it is already a Fish. The Selachians, though showing some noteworthy features of high grade, are the Fishes which most resemble the Marsipobranchs, and which would be expected to be the earliest of true Fishes. The Teleosts, now the most abundant of Fishes, are wanting in Paleozoic and early Mesozoic time. As the most specialized of Fishes, it would naturally be expected that they would be a late development.

Economic Products; Mineral Oil and Gas. — The oil wells of Enniskillen, Canada, as already stated, are in the Corniferous; but the "oil horizon" of Pennsylvania, the most important in North America, belongs to the Upper Devonian. The oil region forms a belt about 40 miles wide, extending across western Pennsylvania, from Monongalia County, West Virginia, to Allegany County, New York. This belt contains many productive areas, and hundreds of oil wells. In 1891 the wells near Bradford, in McKean County, yielded nearly 5½ millions of barrels of oil; those of Allegheny County, in which Pittsburg is situated, yielded over 10⅓ millions; and all western Pennsylvania nearly 32 millions. All the other oil regions of the United States yielded in 1891 about 22 millions, and of this 17¾ millions were from Ohio. A barrel holds 42 gallons. The rock to which the Pennsylvania wells descend is usually a coarse and very porous sandstone; the oil is in its pores. It is supposed by most writers on the subject that the oil in the "oil sands" was derived from subjacent black or carbonaceous shales, like the Genesee or Marcellus, by means of a gentle heating of the rocks during a period of upturning, and that it became condensed in the pores or cavities of the rocks above. Such shales, like coal, do not contain the oil, at least not in large quantity; but they contain hydrocarbon compounds which yield oil when heated. But others have thought that the "oil sands" originally contained the vegetable or animal debris from which the contained oil was made by decomposition. A third view is that the oil has ascended into the porous sandstones by hydrostatic pressure from underlying shales in which it was formed. On any view, the oil is derived directly or indirectly from the decomposition of organic materials. The gas comes from the same regions as the oil. But it appears to be mostly obtained from anticlinal belts, since it rises above the heavier oil and water contained in the porous strata to the highest parts of those strata.

III. CARBONIFEROUS ERA.

GENERAL CHARACTERISTICS: SUBDIVISIONS.

The Carboniferous era was remarkable, in general, for:—

1. A low elevation of large areas of the continents above the sea level, alternating with shallow submergences of the same.

2. Extensive marshy or fresh-water areas over large portions of these low continents.

3. Luxuriant vegetation, covering the land with forests and jungles.

4. A great increase in terrestrial animal life — Snails, Scorpions, Spiders, Centipedes, Insects, over the land, and Amphibians in the marshes. In the closing period of the era, true Reptiles appeared.

But, while having these as its main characteristics, it was not an age of continuous verdure. There was, first, a long period — the *Subcarboniferous* — in which the land was largely beneath the sea; for limestone, full of marine fossils, is the prevailing rock, and there are but few, and mostly thin, coal beds intercalated among the sandstones and shales. This period was followed by the *Carboniferous*, or that of the true Coal Measures. Yet, even in this middle period of the era, there were alternations of submerged with emerged continents, long times of dry and marshy lands luxuriantly overgrown with shrubbery and forest trees, intervening between other long times of great continental seas. Then there was a closing period — the *Permian*, — in which the ocean prevailed again, though with narrower limits than in the Subcarboniferous; for the rocks are mainly of marine origin.

The Carboniferous era and period were so named from the fact that most of the great coal beds of the world originated during their progress. The term *Permian* was given to the rocks of the third period by Murchison, De Verneuil, and Keyserling, from a region of Permian rocks in Russia, the ancient country of Permia, a part of which now constitutes the government of Perm.

DISTRIBUTION OF CARBONIFEROUS ROCKS.

The Carboniferous areas on the map of the United States (page 235) are the dark areas; the heavily cross-lined areas being the Subcarboniferous; the pure black, the Carboniferous and Permian.

some limestone — the estimated thickness 6000 feet. In Michigan and Ohio the Subcarboniferous rocks yield brines, which are used for the manufacture of salt.

The prevailing rock in Great Britain and Europe is a limestone, called the Mountain Limestone. In Northumberland and Scotland, the Subcarboniferous consists chiefly of sandstones, and contains productive coal beds.

2. **Carboniferous Period.** — The base of the series of Carboniferous rocks is generally formed by a hard, gritty sandstone or conglomerate, called in England the Millstone Grit from its frequent use for millstones. A similar rock in Pennsylvania is called the Pottsville Conglomerate. In the center of the Anthracite region it attains a thickness of 800 to 1700 feet, but thins out westward. In parts of Pennsylvania the Pottsville Conglomerate contains beds of coal. In Nova Scotia, the Millstone Grit is 5000 to 6000 feet thick.

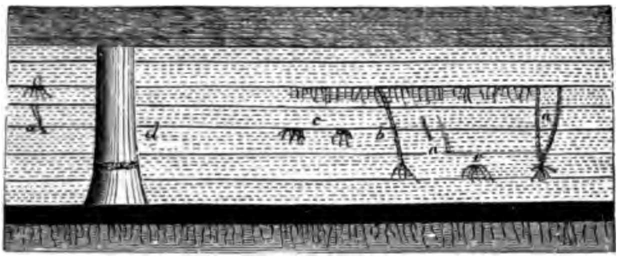
This conglomerate is overlain by the Coal Measures proper. The rocks of the Coal Measures are sandstones, shales, conglomerates, and occasionally limestones; and they are so similar to the rocks of the Devonian and Silurian ages that they cannot be distinguished except by the fossils. They occur in various alternations, with an occasional bed of coal between them. The coal beds, taken together, generally make up not more than one fiftieth of the whole thickness; that is, there are in general 50 feet or more of barren rock to 1 foot of coal. The maximum thickness in Pennsylvania is nearly 3000 feet; in Nova Scotia, about 5000 feet.

Although coal beds may occur in any part of the Coal Measures, they are often very unequally distributed through the series. In Pennsylvania three divisions of the series are recognized: (1) the Lower Productive Measures, (2) the Lower Barren Measures, (3) the Upper Productive Measures. The second of these divisions contains only thin and insignificant coal beds. The Upper Barren Measures, overlying the Upper Productive Measures, belong to the Permian. In the coal field of South Wales, the Coal Measures are similarly divided into two parts by a great thickness of barren sandstone.

The limestone strata are more numerous and extensive in the Central Interior region than in the Appalachian; west of the states of Missouri and Kansas, limestone is the prevailing rock. In Kansas and in West Virginia the rocks afford brines.

Beds of argillaceous iron ore or clay ironstone are very common in coal districts, so that the same region affords ore and the coal for smelting it. Some of the largest iron works in the world, on both sides of the Atlantic, occur

Fig. 306.



Section of a portion of the Coal Measures at the Joggins, Nova Scotia, having erect stumps, and also roots in the underclays.

in coal districts. The ore is usually siderite, or iron carbonate (more rarely, limonite), impure from mixture with some earth or clay.

The coal beds often rest on a bed of grayish or bluish clay, called the *underclay*, which is filled with the roots or underground stems of plants. When this underclay is absent, the rock below is usually a sandstone or a shale. Above the coal bed the rock may be sandstone, shale, conglomerate, or even limestone; often the layer next above, especially if shaly, is filled with fossil leaves and stems. In some cases, trunks of old trees rise from the coal and extend up through overlying beds, as shown in Fig. 306, by Dawson, from the Nova Scotia Coal Measures. Occa-

Manchester and Liverpool; the Yorkshire, about Leeds and Sheffield; and the Newcastle. In South Wales the thickness of the Coal Measures is 7000 to 12,000 feet, with more than 100 coal beds, 70 of which are worked.

Scotland has some small areas between the Grampian range on the north and the Lammermuirs on the south; and Ireland, several coal regions of large extent.

The coal fields of the continent of Europe that are most worked are the Belgian, bordering on and passing into France. Germany contains small coal-bearing areas in Rhenish Prussia, Westphalia, and Silesia. Russia in Europe affords very little coal, although rocks of the Carboniferous era cover large portions of the surface.

The area of the Coal Measures in Great Britain and Ireland is about 12,000 square miles; in Spain, 4000; in France, 2000; Germany, 1800; Belgium, 518.

Coal beds of Carboniferous age occur also in China and in Spitzbergen. Valuable coal beds of Permian age occur in India (in the Lower Gondwana series) and in Australia.

Valuable coal beds are not found in any rocks older than those of the Carboniferous era, although black carbonaceous shales are not uncommon even in the Lower Silurian. They occur, however, in various Mesozoic formations, and also in the Cenozoic, but not on so extensive a scale as in the Carboniferous formations.

KINDS OF ROCKS.

1. **Subcarboniferous Period.** — The Subcarboniferous strata in the Central Interior region are mainly limestone; and, as the limestone abounds in many places in Crinoidal remains, the rock is often called the Crinoidal Limestone. In the Appalachian region, in southwestern Virginia, Tennessee, and Alabama, the rock is also in large part limestone, and has great thickness; but farther north, in West Virginia and Pennsylvania, it is mostly a sandstone or conglomerate (Pocono group), overlain by shaly sandstones and shales of reddish and other colors (Mauch Chunk group)

ture when it is held up to the light. This structure is absent in the variety called cannel coal, which is a bituminous coal, very compact in texture, feeble in luster, and smooth in fracture.

3. **Permian Period.** — The upper part of the Carboniferous formation (Upper Barren Measures) of Pennsylvania and Virginia has been shown by its fossil plants, and that of Illinois, Kansas, and Texas, by its Reptiles and Mollusks, to be Permian. The uppermost strata in the Acadian Coal area also are Permian. Permian strata occur also in the Rocky Mountain region. The rocks are mostly reddish and gray sandstones and shales, with some impure limestone. The Permian strata of Texas have been included with the Triassic, under the name *Red Beds*. In Kansas the rocks include a large amount of limestone. Similar red and gray sandstones and shales occur in Great Britain, in the vicinity of several of the Coal regions, and also in Germany and Russia. The Permian rocks of Great Britain were formerly included with the Triassic under the name *New Red Sandstone*.

In India and in Australia, the Permian formation contains valuable beds of coal.

In England, India, Australia, South Africa, and southern Brazil, the Permian includes a conglomerate with bowlders of great size, some of which show subangular forms and smoothed and striated surfaces, like those of glaciated bowlders (pages 164, 408). While some geologists have not hesitated to infer the existence of a glacial climate in those regions, others believe that a conclusion so startling requires confirmation.

LIFE.

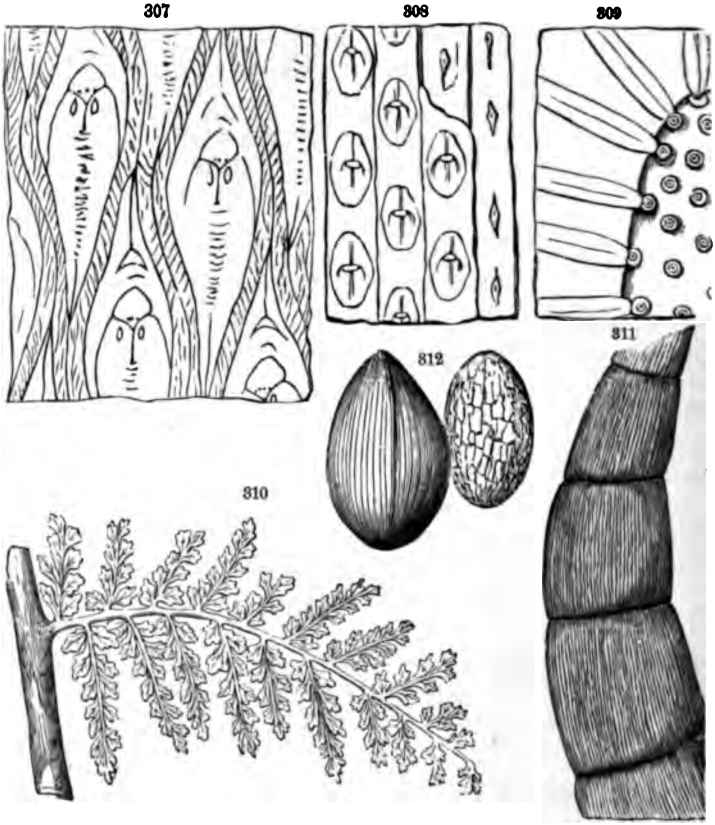
PLANTS.

The plants of the forests, jungles, and floating islands of the Carboniferous age, thus far made known, number nearly 2000 species. Among the fossils there are none

[redacted]

that afford satisfactory evidence of the presence of Angiosperms. There were no Oaks, nor Maples, nor Palms in the forests, and the plains were without grass. At the

FIGS. 307–312.



ACROGENS: Fig. 307, Lepidodendron aculeatum; 308, Sigillaria oculata; 309, Stigmaria ficoides; 310, Sphenopteris Gravenhorstii; 311, Calamites cannæformis. — GYMNOSPERM: Fig. 312, Trigonocarpus.

present day, Angiosperms, along with Conifers, make up the great bulk of our shrubs and trees; Palms abound in all tropical countries; and grass covers all exposed slopes where the climate is not too arid.

Cryptogams. — The Carboniferous species, like their predecessors in the Devonian age, belonged mostly to the following groups: —

1. *Ferns.* — Ferns were very abundant, a large part of the fossils of a coal region being their delicate fronds, or leaves. A portion of a fossil Fern is represented in Fig. 310. Besides small species, like the common kinds of the present day, there were (as is now the case in the tropics) Tree Ferns — species that had a trunk, perhaps 20 or 30 feet high, which bore at top a radiating tuft of very large fronds. Tree Ferns, however, were not very common in the Carboniferous forests. The scars in fossil or recent Tree Ferns are many times larger than those of Lepidodendrids, and the fossils may be thus distinguished.

2. *Lycopods.* — The *Lepidodendrids* appear to have been among the most abundant of Carboniferous forest trees, especially in the earlier half of the era, or to the middle of the Coal Measures. They probably covered both the marshes and the drier plains and hills. Some of the old logs now preserved in the strata are 50 to 60 feet in length, strikingly contrasting with the little Ground Pines of modern times; and the pinelike leaves were occasionally a foot or more long. Fig. 307 shows the surface markings of one of the species, natural size.

The *Sigillariæ* were a very marked feature of the great jungles and deep forests of the Coal period. They grew to a height sometimes of 30 to 60 feet; but the trunks were seldom branched, and must have had a stiff, clumsy aspect, although covered above with long, slender, rush-like leaves. Fig. 308 represents a common species, exhibiting the usual arrangement of the scars in vertical lines, and also indicating, by the difference between the scars of the right row and the others, their difference of form on the outer surface of the tree and beneath the rind.

The fossil *Stigmariæ* are stout stemlike bodies, generally 2 to 3 or more inches thick, having over the surface distinct rounded depressions, or scars. Fig. 309 is a portion of the extremity of a stem, showing the rounded depressions, and also the appendages (rootlets) whose position, when they have decayed or fallen off, is marked by the scars, and which are occasionally observed in place. The stems are a little irregular in form, and sparingly branched. They have been found spreading, like roots, from the base of the trunk of a *Sigillaria*, and sometimes also from that of a *Lepidodendron;* and they are hence regarded as the roots or rootstocks of these trees. They are an exceedingly common fossil, especially in the underclays of the Coal Measures (page 297).

3. *Equiseta.*—Fig. 311 represents a portion of one of the Tree Rushes, or *Calamites*, of the *Equisetum*, or Horsetail group. These plants were very abundant in the great marshes, through the whole of the era. Some of them were 20 feet or more in height, and 10 or 12 inches in diameter.

Besides these Acrogens, a few remains of Fungi have been found, but, as yet, no remains of Mosses. A Moss, however, could only be preserved as a fossil under very exceptional conditions; and in such a case the negative evidence is of little value.

Phanerogams.—As in the Devonian era, both Conifers and Cycads were probably present. Some of the genera seem to show characters intermediate between these two types.

Trunks of trees, Coniferous in character, are not uncommon.

There are also various nutlike fruits found in the Carboniferous strata. One is represented in Fig. 312 (page 300), the figure to the left being that of the shell, and the other that of the nut which it contained. Some of them are two inches in length. The most of them were probably the fruit of Conifers, but possibly of Cycads.

It is seen from the above that—

1. The vegetation of the Carboniferous era consisted very largely of Cryptogams, or flowerless plants.

2. The flowering plants, or Phanerogams, associated with the flowerless vegetation, were of the class of Gymnosperms, whose flowers are simple and inconspicuous.

3. While, therefore, there was abundant and beautiful foliage (for no foliage exceeds in beauty that of Ferns), the vegetation was nearly flowerless.

4. The characteristic Cryptogams were not only of the highest group of that division of plants, but many of them exceeded in size and in complexity of organization the species of the present day.

ANIMALS.

Cœlenterates. — Fig. 313 presents a view of the upper surface of a very common Coral of the Subcarboniferous period: it has a columnar appearance in a side view.

Echinoderms. — Crinoids were especially numerous in the Subcarboniferous period. Figs. 314–316 represent some of the species. Figs. 314, 315, are Brachiate Crinoids. In the former, the arms are perfect; in the latter, they have been broken off. Fig. 316 is a representative of the Blastoids, a group which commenced in the Upper Silurian, attained its maximum development in the Subcarboniferous, and became extinct at the close of the Carboniferous period.

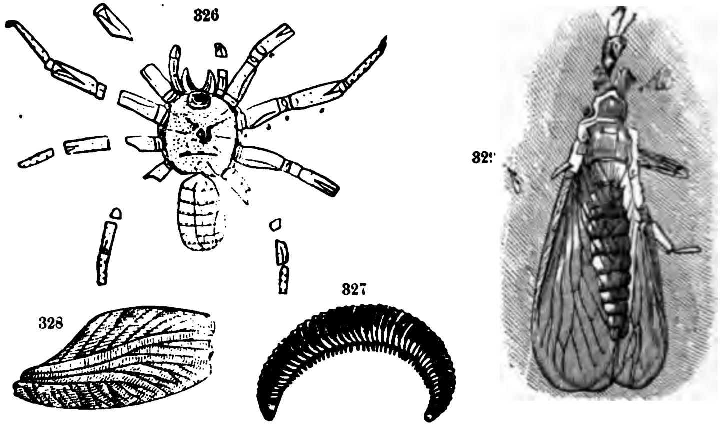
Molluscoids. — The class of Bryozoans included the singular screw-shaped (or auger-shaped) Coral shown in Fig. 317, and named *Archimedes* (referring to Archimedes' screw). The upper, or inner, surface of the spiral lamina shows the orifices of the cells, each of which, when alive, contained a minute individual of the colony (page 70). These fossils are common in some of the Subcarboniferous limestone strata.

Brachiopods were very abundant through the Carboniferous age, and especially species of the genera *Spirifer* and *Productus*. Figs. 318–321 are of species from the American Coal Measures.

or a Neuropter, those two orders being often undistinguishable in fossil condition. The earliest remains of Hemipters occur in the Permian. Remains of Beetles (Coleopters) have been doubtfully reported from the Subcarboniferous of Silesia. With doubtful exceptions, the higher orders of Insects, characterized by passing through an inactive pupa stage (complete metamorphosis), are wanting in the Paleozoic.

Vertebrates. — Fishes were numerous, including Selachians, Ganoids, and Dipnoans. Many of the Selachians

FIGS. 826–829.



ARACHNOID: Fig. 826, Arthrolycosa antiqua. — MYRIOPOD: FIG. 827, Xylobius sigillariæ. — HEXAPODS: Fig. 828, wing of Etoblattina venusta; 829, Miamia Bronsoni.

were of great size, as shown by the fin spines. Fig. 331 represents a small portion of one of these spines, natural size, from the Subcarboniferous beds of Europe. One of the largest specimens of a spine of the same species, when entire, must have been 18 inches long. Nearly all the Ganoids had vertebrated tails, as shown in Fig. 330, which represents a common Permian species.

Amphibians occur throughout the era. They all belong to an order which became extinct at the close of the Triassic or during the Jurassic. Unlike the Frogs and

Cryptogams. — The Carboniferous species, like their predecessors in the Devonian age, belonged mostly to the following groups: —

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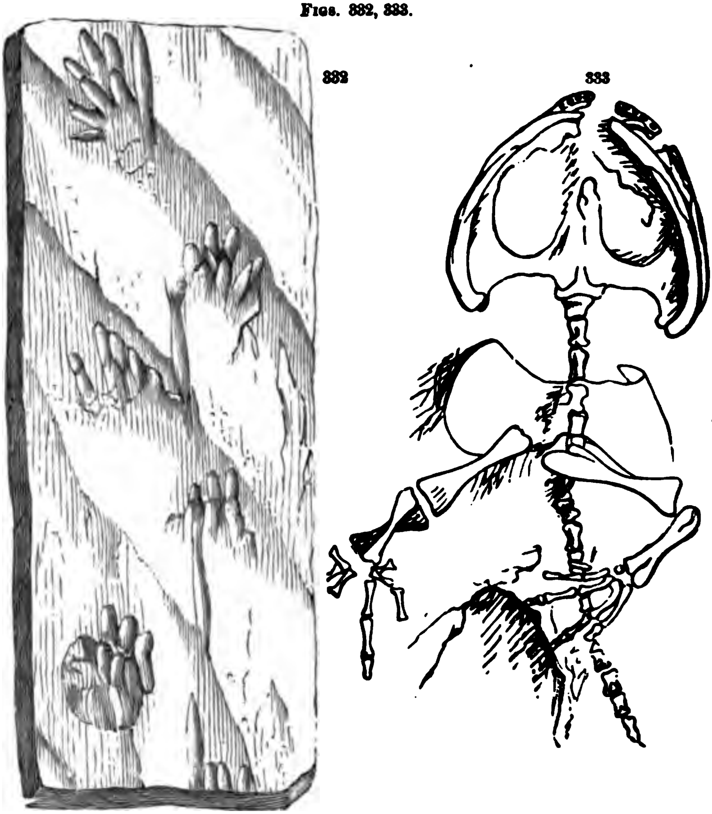
The fossil *Stigmariæ* are stout stemlike bodies, generally 2 to 3 or more inches thick, having over the surface distinct rounded depressions, or scars. Fig. 309 is a portion of

Reptiles made their first appearance in the Permian. Two orders of Reptiles were represented: (1) the *Rhynchocephala*, a group represented by numerous Permian and

FIGS. 332, 333.



AMPHIBIANS: Fig. 332, tracks of Sauropus primævus, × $\frac{1}{8}$; 333, Pelion Lyellii.

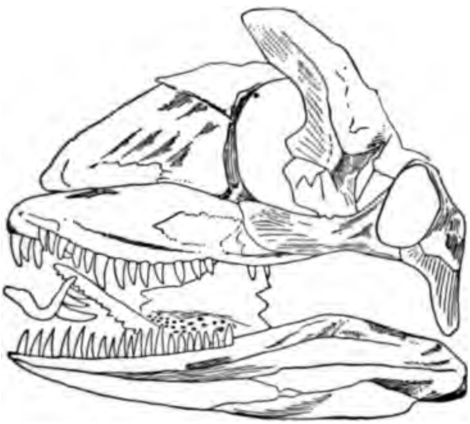
Mesozoic species, but now nearly extinct, a single genus surviving in New Zealand; (2) the *Theromorphs*, a group confined to the Permian and Triassic, remarkable for certain striking resemblances to Mammals, particularly in the skull. Fig. 334 shows the skull of one of the Rhynchocephala, from the Permian of Saxony.

GENERAL OBSERVATIONS.

Mode of Formation of the Coal Measures. — *Origin of the Coal.* — The vegetable origin of coal is proved by the following facts:—

1. Trunks of trees, still retaining the original form and part of the structure of the wood, have been found changed to mineral coal, both in the Carboniferous strata and in more modern formations, showing that the change may and does take place.

FIG. 334.



REPTILE: Palæohatteria longicaudata.

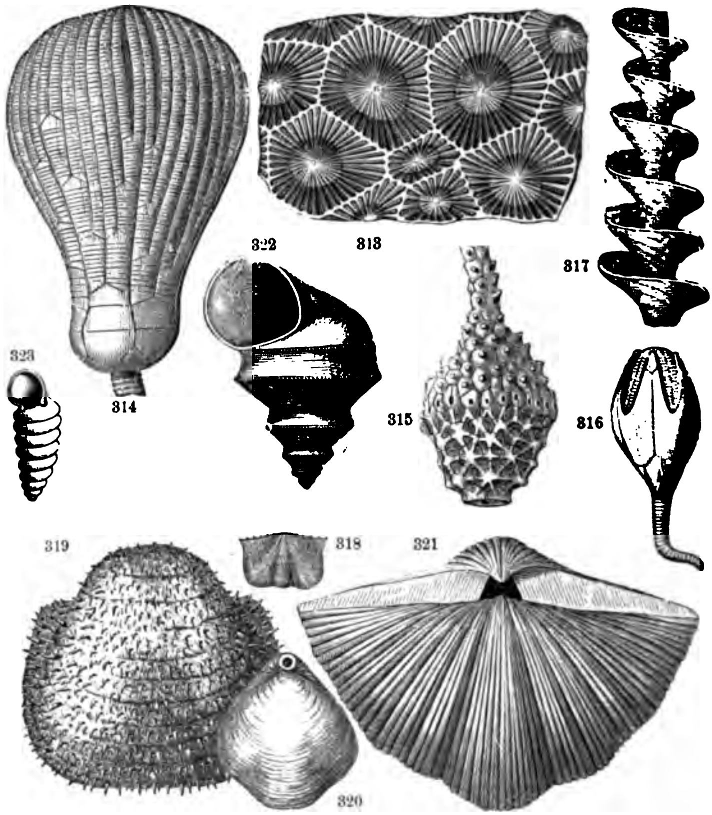
2. Beds of peat, a result of vegetable growth and accumulation, exist in modern marshes; and in some cases they are altered below to an imperfect coal. (See page 107, on the formation of peat.)

3. Remains of plants — leaves, branches, and stems or trunks — abound in the Coal Measures; trunks sometimes extend upward from a coal bed into and through some of the overlying beds of rock; roots or stems abound in the underclays.

4. The hardest anthracite contains throughout its mass vegetable tissues. Professor Bailey examined with a high magnifying power several pieces of anthracite burnt at one end, like Fig. 335, taking fragments from the junction of the white and the black portion, and readily detected the tissues. Fig. 336 represents the ducts, as they

Mollusks. — Fig. 322 represents one of the marine Gastropods of the Coal Measures. Fig. 323 is a *Pupa*, the earli-

FIGS. 313–323.



ANTHOZOAN: Fig. 313, Lithostrotion Canadense. — CRINOIDS: Fig. 314, Woodocrinus elegans; 315, Actinocrinus proboscidialis; 316, Pentremites pyriformis. - BRYOZOAN: Fig. 317, Archimedes Wortheni. — BRACHIOPODS: 318, Chonetes mesolobus; 319, Productus Nebrascensis; 320, Athyris subtilita; 321, Spirifer cameratus. — GASTROPODS: 322, Pleurotomaria tabulata; 323, Pupa vetusta.

est yet found of Land Snails: it is from the Coal Measures of Nova Scotia; others have been found in Illinois. The class of Cephalopods was represented by few and small combustion is incomplete, and coal may result, consisting of the unconsumed carbon combined with some hydrogen and oxygen.

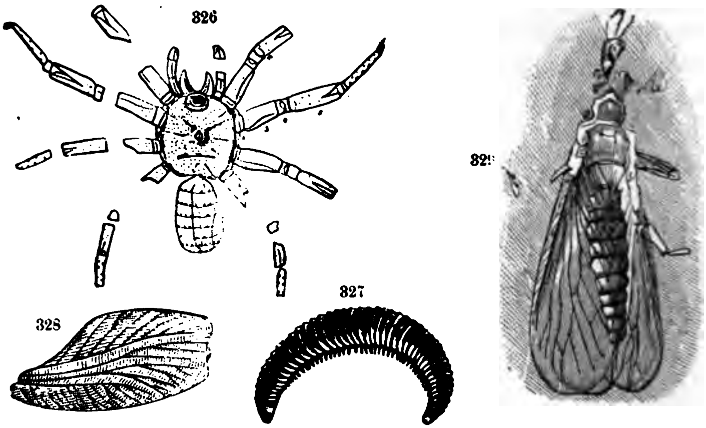
The actual loss, by weight, in conversion into bituminous coal, is at least three fifths of the wood, and, in conversion into anthracite, three fourths. Adding to this loss that from compression, by which the material is brought to the density of mineral coal, the whole reduction in bulk is not less than four fifths for the former, and seven eighths for the latter. In other words, it would take 5 cubic feet of vegetable matter to make 1 of bituminous coal, and 8 feet to make 1 of anthracite.

Impurities in Coal. — The coal thus formed derived some silica and other earthy ingredients from the wood itself, including probably, in the case of the Lepidodendrids, some alumina, since this earth exists in the ash of modern Lycopods. From this source the best coal received some earthy impurities, while the poorer coals contain, in addition, clay or earthy material carried over the marshes by the waters or winds. Sulphur is a common impurity; it usually occurs combined with iron, forming pyrite, or sulphide of iron.

Accumulation and Formation of Coal Beds. — The origin of coal beds was, then, as follows: The plants of the great marshes and shallow lakes of the Carboniferous period, the latter with their floating islands of vegetation, continued growing for a long period, dropping annually their leaves, and from time to time decaying stems or branches, until a thick accumulation of vegetable remains was formed — probably 5 feet in thickness for a one-foot bed of bituminous coal. The bed of material thus prepared over the vast wet areas of the continent early commenced to undergo at bottom that slow decomposition the final result of which is mineral coal. But the alternation of the coal beds with sandstones, shales, conglomerates, and limestones, shows that the long period of verdure was followed by a period of overflowing waters, which disor a Neuropter, those two orders being often undistinguishable in fossil condition. The earliest remains of Hemipters occur in the Permian. Remains of Beetles (Coleopters) have been doubtfully reported from the Subcarboniferous of Silesia. With doubtful exceptions, the higher orders of Insects, characterized by passing through an inactive pupa stage (complete metamorphosis), are wanting in the Paleozoic.

Vertebrates. — Fishes were numerous, including Selachians, Ganoids, and Dipnoans. Many of the Selachians

FIGS. 326–329.



ARACHNOID: Fig. 326, Arthrolycosa antiqua. — MYRIOPOD: FIG. 327, Xylobius sigillariæ. — HEXAPODS: Fig. 328, wing of Etoblattina venusta; 329, Miamia Bronsoni.

were of great size, as shown by the fin spines. Fig. 331 represents a small portion of one of these spines, natural size, from the Subcarboniferous beds of Europe. One of the largest specimens of a spine of the same species, when entire, must have been 18 inches long. Nearly all the Ganoids had vertebrated tails, as shown in Fig. 330, which represents a common Permian species.

Amphibians occur throughout the era. They all belong to an order which became extinct at the close of the Triassic or during the Jurassic. Unlike the Frogs and dioxide permanently withdrawn from the atmosphere by the coal plants. The growth of the flora of that age was a means of purifying the atmosphere, so as to fit it for the higher terrestrial life that was afterward to possess the world. The amount of carbon dioxide lost by the atmosphere in the formation of carbonate of lime and other carbonates, in the course of geological time, is even greater than the loss by means of vegetation. (See page 236.)

Again, the atmosphere was more moist than now. This follows from the greater warmth of the climate, and the greater extent and higher temperature of the oceans. The land areas, although large, during the times of verdure, compared with the land areas of the Devonian or Silurian, were still small, and the land low. It must, therefore, have been an era of prevailing clouds and mists and abundant rains. But then, as now, there must have been inequalities in the distribution of rain. America is now the moist forest continent of the globe; and the great extent of the coal fields of its northern half suggests that it may have borne the same character in the Carboniferous age.

Geography. — *Appalachian and Rocky Mountains not yet made.* — On page 290 it is stated that the continents in this age were low, with few mountains. The nonexistence of the Appalachians of Pennsylvania and Virginia is proved by the fact that Carboniferous rocks make up a part of the mass of these mountains — partly marine rocks, indicating that the sea then spread over the region; partly coal beds, each bed evidence that a great fresh-water marsh, flat as all marshes are, for a long while occupied the region of the present mountains.

There is the same evidence that the mass of the Rocky Mountains had not been lifted; for marine Carboniferous rocks constitute a large part of these mountains, many beds containing remains of the life of the Carboniferous seas that covered that part of North America. Only

South Carolina, Georgia, Alabama, and northern Mississippi, then turn northward around the bay which occupied the lower Mississippi Valley, then southward around the southern end of the Carboniferous area in Texas; thence the coast line would stretch northward, bounding a sea covering a large part of the Rocky Mountain region, for the Coal period was, in that part of the continent, mainly a time of limestone-making. On the contrary, in a map representing the continent during the succeeding times of submergence, the coast line would be nearly as laid down in the map, Fig. 303, page 287. Through these conditions, as the extremes, the continent may have passed several times in the course of the Carboniferous period. Many of the oscillations, however, may have affected only parts of the continent, some parts of the Carboniferous area being submerged while other parts were clothed with vegetation.

Condition in the Permian Period. — Finally, in the Permian period, the continent seems in some degree to have reverted to a condition of submergence like that of the Subcarboniferous, the coal beds being insignificant.

GENERAL OBSERVATIONS ON THE PALEOZOIC.

Rocks. — 1. *Maximum Thickness.* — The maximum thickness of the rocks of the various Paleozoic eras in North America is approximately estimated as follows: — Cambrian, 20,000 feet; Lower Silurian, 18,000; Upper Silurian, 7000; Devonian, 14,000; Carboniferous, 16,000.

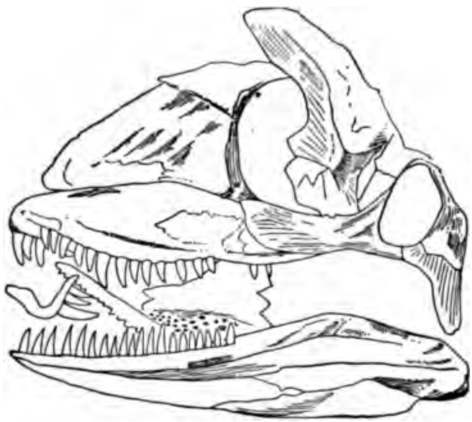
2. *Diversities of the Different Continental Regions as to Kinds of Rocks.* — The Paleozoic rocks of the Appalachian region are mainly sandstones, shales, and conglomerates; only about one fourth of the whole thickness consists of limestone. The rocks of the Central Interior are mostly limestone, fully two thirds being of this nature.

In the Central Interior, the Cambrian rocks are largely limestones; those of the Lower Silurian, even those of

GENERAL OBSERVATIONS.

Mode of Formation of the Coal Measures. — *Origin of the Coal.* — The vegetable origin of coal is proved by the following facts:—

Fig. 334.



Reptile: Palæohatteria longicaudata.

1. Trunks of trees, still retaining the original form and part of the structure of the wood, have been found changed to mineral coal, both in the Carboniferous strata and in more modern formations, showing that the change may and does take place.

2. Beds of peat, a result of vegetable growth and accumulation, exist in modern marshes; and in some cases they are altered below to an imperfect coal. (See page 107, on the formation of peat.)

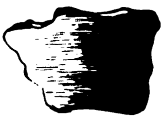
3. Remains of plants — leaves, branches, and stems or trunks — abound in the Coal Measures; trunks sometimes extend upward from a coal bed into and through some of the overlying beds of rock; roots or stems abound in the underclays.

4. The hardest anthracite contains throughout its mass vegetable tissues. Professor Bailey examined with a high magnifying power several pieces of anthracite burnt at one end, like Fig. 335, taking fragments from the junction of the white and the black portion, and readily detected the tissues. Fig. 336 represents the ducts, as they

appeared in one case under his microscope; and Fig. 337, part of the same, more magnified. Fig. 338 shows the appearance of the spores of Lycopods (Lepidodendrids) much magnified; they are common in coal.

FIGS. 335-337.

335



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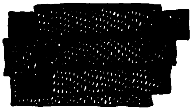

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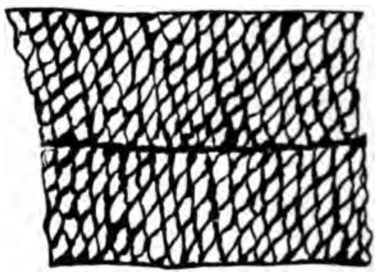

Vegetable tissues in anthracite.

Decomposition of Vegetable Material. — The mineral coal of the Coal Measures consists (impurities excluded) of 65 to 93 per cent of carbon, along with 2 to 9 of hydrogen, and 2 to 17 of oxygen; and woody material, whether of Conifers, Ferns, Lycopods, or Equiseta, consists of about 45 per cent of carbon, 6 of hydrogen, and 49 of oxygen. To change the vegetable material to coal, it is necessary to get rid of part of the oxygen and hydrogen. Vegetable matter decomposing in the open air — like wood burnt in an open fire — is completely oxidized, and passes off as water vapor and carbon dioxide. Both the oxygen of the air and that of the wood take part in the combustion or decomposition. But, if the former is more or less excluded by a covering of earth or of water (as in a swamp), the

FIG. 338.

Spores and part of a sporangium of Lepidodendron in bituminous coal of Ohio, × 70.

combustion is incomplete, and coal may result, consisting of the unconsumed carbon combined with some hydrogen and oxygen.

The actual loss, by weight, in conversion into bituminous coal, is at least three fifths of the wood, and, in conversion into anthracite, three fourths. Adding to this loss that from compression, by which the material is brought to the density of mineral coal, the whole reduction in bulk is not less than four fifths for the former, and seven eighths for the latter. In other words, it would take 5 cubic feet of vegetable matter to make 1 of bituminous coal, and 8 feet to make 1 of anthracite.

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Climate of the Age. — The wide distribution of the coal regions over the globe, from the tropics to remote Arctic lands, and the general similarity of the vegetable remains in the coal beds of these distant zones, prove that there was a general uniformity of climate over the globe in the Carboniferous period, or at least that the climate was nowhere colder than warm-temperate. Besides, corals and shells existed during the Subcarboniferous period in Europe, the United States, and the Arctic regions within 20° of the North Pole, and so profusely as to form thick limestones out of their accumulations; and some Arctic species are identical with those of Europe and America. The ocean's waters, even in the far north, were, therefore, warm compared with those of the modern temperate zone, and probably quite as warm as the coral-reef seas of the present age, which lie mostly between the parallels of 28° either side of the equator. This uniform warm climate appears to have characterized the whole of the Paleozoic, no clearly defined climatic zones being indicated until a later period. Whether the bowlder beds of the Permian (page 299) will require modification of current opinions regarding Paleozoic climate, is at present matter of doubt.

Atmosphere.—The atmosphere contained a larger amount than now of carbon dioxide — the gas from which plants derive their carbon. The mineral coal of the world is approximately a measure of the amount of carbon

Canada and New York, probably began their flow along its upper portion, and emptied into the St. Lawrence Gulf of the time not far below Montreal.

The Hudson-Champlain Valley apparently dates from Archæan time, and was a salt-water channel in the Lower Silurian. At the close of the Lower Silurian the channel was closed by the elevation of the region, but it was probably temporarily reopened in the Lower Helderberg period. The Hudson River must have commenced at the close of the Lower Silurian, as an insignificant stream, draining a part of the Adirondacks, and emptying into the Eastern Interior sea near Albany.

An embryo Mississippi River probably began early in Paleozoic time to drain the Archæan regions of Wisconsin and Minnesota. But the main part of the Mississippi and its tributaries, east and west, was not in existence in the Paleozoic ages. In the times of Carboniferous verdure, when the continent was in large part above the sea level, the Ohio and Mississippi basins were regions of great marshes, lakes, and bayous, and not of great rivers; for great rivers could not exist without high land to supply water and give it a flow.

Climate. — No evidence has been found through the Paleozoic records of any marked difference of temperature between the zones. In the Carboniferous era the Arctic seas had their Corals and Brachiopods, and the Arctic lands their forests and marshes under dense foliage, no less than those of America and Europe. The facts bearing on this subject are stated on page 312.

Life. — *Appearance and Disappearance of Species.* — With the beginning of each formation in the series, new species appeared, and the old ones more or less completely disappeared. Local changes in the life occurred in connection even with the minor transitions in the rock formations, as in the transition from a bed of shale to sandstone or to limestone, and the reverse. Thus, through the ages, life and death were in concurrent progress.

islands, or archipelagoes, made by Archæan, and perhaps also Paleozoic, ridges, existed in the midst of the widespread western waters.

Condition in the Subcarboniferous Period. — Through the first period of this era, — the Subcarboniferous, — the continent was almost as extensively beneath the sea as in the Devonian. This is shown by the nature and extent of the Subcarboniferous rocks — the great Crinoidal Limestones.

Transition to the Carboniferous Period. — Finally, the Subcarboniferous period closed, and the Carboniferous opened. But, in the transition from the period of submergence to that of emergence, required to bring into existence the great marshes, a widespread bed of pebbles, gravel, and sand was accumulated by the waves dashing rudely over the surface of the rising continent; and these pebble beds make the Pottsville Conglomerate, or Millstone Grit, that marks the commencement of the Carboniferous period in a large part of eastern North America, especially along the Appalachian region, and also in Europe.

Coal-plant Areas in the Carboniferous Period. — The positions of the great Coal areas of North America (see map, page 235) are the positions, beyond question, of the great marshes and shallow fresh-water lakes of the period. But it is probable that the number of these marshes was less than that of the coal areas. The Appalachian, Illinois-Indiana, and Iowa-Texas fields may have made one vast Interior Continental marsh region, and those of Rhode Island, Nova Scotia, and New Brunswick an Atlantic Border marsh region, connected over Massachusetts Bay and the Bay of Fundy. It may be, however, that a low area of dry land extending from the region of Cincinnati southward across Kentucky nearly or quite separated the Eastern Interior, from the Central Interior, marsh.

The Michigan marsh region appears also to have had its dry margins, instead of coalescing with the Illinois-Indiana or the Appalachian area.

It is not to be inferred that the marshes alone were covered with verdure. The vegetation probably spread over all the dry land, though making thick deposits of vegetable remains only where there were marshes under dense jungles and shallow lakes with their floating islands.

Alternations of Condition; Changes of Level. — It has been remarked that the many alternations of the coal beds with sandstones, shales, conglomerates, and limestones (page 311), are evidence of as many alternations of level, or at least alternations of condition, during the era. After the great marshes of the Continental Interior had been long under verdure, the salt waters began again to encroach upon them in consequence of a sinking of the land, and finally swept over the whole surface, destroying the terrestrial and fresh-water life of the area, but distributing at the same time the new life of the salt waters. Then, after another long period, one perhaps of many oscillations in the water level, in which sedimentary beds in many alternations were formed, the continent again rose to aërial life, and the marshes and shallow lakes were luxuriant anew with the Carboniferous vegetation. Thus the sea prevailed at intervals — intervals of long duration — through the era even of the Coal Measures; for the associated sedimentary beds, as has been stated, are in most localities at least fifty times as thick as the coal beds. In the Nova Scotia Coal area, the waters which came in over the coal beds were the brackish or fresh waters of a great estuary — that at the mouth of the St. Lawrence River of the Carboniferous period.

These oscillations continued until nearly 3000 feet of strata were formed in some parts of Pennsylvania, and about 5000 in Nova Scotia.

The Carboniferous period was, therefore, ever varying in its geography. A map of its condition when the great coal beds were accumulating would have its eastern coast line, from the Carolinas northward, even outside of the present. The southern coast line would pass through

South Carolina, Georgia, Alabama, and northern Mississippi, then turn northward around the bay which occupied the lower Mississippi Valley, then southward around the southern end of the Carboniferous area in Texas; thence the coast line would stretch northward, bounding a sea covering a large part of the Rocky Mountain region, for the Coal period was, in that part of the continent, mainly a time of limestone-making. On the contrary, in a map representing the continent during the succeeding times of submergence, the coast line would be nearly as laid down in the map, Fig. 303, page 287. Through these conditions, as the extremes, the continent may have passed several times in the course of the Carboniferous period. Many of the oscillations, however, may have affected only parts of the continent, some parts of the Carboniferous area being submerged while other parts were clothed with vegetation.

Condition in the Permian Period. — Finally, in the Permian period, the continent seems in some degree to have reverted to a condition of submergence like that of the Subcarboniferous, the coal beds being insignificant.

GENERAL OBSERVATIONS ON THE PALEOZOIC.

Rocks. — 1. *Maximum Thickness.* — The maximum thickness of the rocks of the various Paleozoic eras in North America is approximately estimated as follows: — Cambrian, 20,000 feet; Lower Silurian, 18,000; Upper Silurian, 7000; Devonian, 14,000; Carboniferous, 16,000.

2. *Diversities of the Different Continental Regions as to Kinds of Rocks.* — The Paleozoic rocks of the Appalachian region are mainly sandstones, shales, and conglomerates; only about one fourth of the whole thickness consists of limestone. The rocks of the Central Interior are mostly limestone, fully two thirds being of this nature.

In the Central Interior, the Cambrian rocks are largely limestones; those of the Lower Silurian, even those of the Hudson epoch, are mostly limestones; the Upper Silurian and Devonian are represented by an almost continuous series of limestones, excepting the Upper Devonian, which is represented by the "Black Shale"; the Subcarboniferous consists mostly of limestone; and the Coal Measures include a much larger proportion of limestone than in the Appalachian region.

3. *Diversities of the Appalachian and Central Interior Regions as to the Thickness of the Rocks.* — In the Appalachian region the maximum thickness of the Paleozoic rocks is more than 40,000 feet. But this thickness is not observed at any one locality, being obtained by adding together the greatest thicknesses of the several formations wherever observed. The greatest actual thickness in Pennsylvania is about 30,000 feet, or nearly six miles.

In the central portions of the Interior region the thickness varies from 3000 to 6000 feet; and it is, therefore, from one sixth to one tenth that in the Appalachian region.

Time Ratios. — Judging from the maximum thickness of the rocks of the several Paleozoic ages in North America, and assuming that five feet of fragmental rocks may accumulate in the time required for one foot of limestone, the relative lengths of the Eopaleozoic, Upper Silurian, Devonian, and Carboniferous ages were not far from 6 : 1 : 2 : 2.

The method of computation is, however, essentially uncertain, since thickness of sediment must depend on amount of subsidence. In a locality which was not subsiding, thick sediments could not accumulate, even in infinite time. But the estimates are so far reliable as to show clearly that time moved on slowly in the earth's first beginnings.

Geography. — *Close of Archæan Time.* — The map on page 237 shows approximately the outline of the dry land of North America at the close of the Archæan. The only mountains were Archæan mountains, among the chief of which were the Laurentian Mountains of Canada, the Adirondacks of northern New York, the Highlands of southeastern New York and New Jersey, the long Archæan range whose degraded remnant is seen in the "Piedmont belt" of the South Atlantic states, and the still longer range which forms the "backbone" of the Rocky Mountains. We cannot judge of the height of these mountains then from what we now see, after all the ages of Geology have passed over them, for the atmosphere and water have never ceased action since the time of their uplift, and the amount of loss by degradation must have been very great; while, on the other hand, the altitude of Archæan ranges in the Appalachian and Rocky Mountain regions may have been increased by orogenic movements of those regions in later time.

General Progress through Paleozoic Time. — The increase of dry land during the Paleozoic has been shown (pages 272, 287) to have taken place mainly along the borders of the Archæan, so that the original area was thus gradually extending. This increase is well marked from north to south across New York. At the close of the Lower Silurian the shore line was not far from the present position of the Mohawk, indicating but a slight extension of the dry land in the course of this very long era; when the Upper Silurian ended, the shore line was probably about a score of miles south of the Mohawk. When the Devonian ended and the Carboniferous age was about opening, the coast line was just north of the Pennsylvania boundary. The progress southward went on in like manner in Wisconsin, where there is an isolated Archæan region like that of northern New York. By the close of the Lower Silurian, the great Cincinnati island had emerged; and, by the close of the Devonian, that island had become a peninsula connecting with the mainland in the region of northern Illinois. (See map, Fig. 303, page 287.) The region of the southern peninsula of Michigan continued through the Subcarboniferous and the times of submergence in the Carboniferous to be the head of the great Eastern Interior bay of the Continental sea. In the times of emergence, the Michigan bay became a marsh or fresh-water lake, filled with Coal-measure vegetation; and, at the same times, as explained on page 315, the continent east of the western meridian of Missouri had nearly its present extent, though not its mountains nor its rivers.

Regions of Rock-making and their Differences. — During most of Paleozoic time, the greater part of the continent was submerged beneath marine waters, and that part was the scene of nearly all the rock-making. Areas of fresh water, however, existed at times, especially in the Devonian and Carboniferous, as is proved by the coal beds, and by occasional fresh-water shells in shales and sandstones.

After the emergence of the Cincinnati and Tennessee islands, at the close of the Lower Silurian, the Interior Continental sea (as explained on page 263) was divided into a Central Interior sea and an Eastern Interior sea or bay. The eastern part of the latter occupied the region of the Appalachian geosyncline.

The Central Interior region afforded the conditions fitted for the growth of Corals and Crinoids and other clear-water species, and hence for the making of limestones out of their remains; for limestones are the principal rocks of the interior. Yet there were oscillations in the level; for there are abrupt transitions in the limestones, and some sandstones and shales alternate with them. But these oscillations were not great, the whole thickness of the rocks, as stated on page 317, being small.

The Appalachian region, on the contrary, presented the conditions required for fragmental deposits. It was apparently a region of immense sand reefs and mud flats, with bays, estuaries, and extensive submerged offshore plateaus. Here the change of level was very great; for within this region occur nearly six miles of Paleozoic formations (page 317). This vast thickness indicates that, while there were various upward and downward movements over this Appalachian region through Paleozoic time, the downward movements exceeded the upward even by the amount just stated.

Mountains of Paleozoic Origin. — The formation of the Taconic system of mountains (page 261), and the emergence of the Atlantic Border region from southern New England to Georgia (page 262), are the most marked geographical changes which occurred during Paleozoic time. The Taconic range itself extends along the northwestern and western boundary of New England, from Canada to northwestern Connecticut. But it was apparently only one of a system of approximately parallel contemporaneous ranges extending southwestward to Virginia and perhaps still farther. As in the case of the still earlier Archæan ranges, the original altitude of these ranges of the Taconic system is matter for mere conjecture. They have suffered ages of erosion, but they may have been re-elevated in later orogenic movements. The region of western New England and eastern New York was not so much elevated at the time of the Taconic movements, as to prevent the deposit of marine strata in part of the Hudson Valley in the Upper Silurian, and in the Connecticut Valley even in the Devonian.

Near Gaspé in eastern Canada, and in Maine, New Brunswick, and Nova Scotia, the unconformability between the Devonian and the Carboniferous indicates some mountain-making movements at the close of the Devonian.

Rivers; Lakes. — The depression between the New York and the Canada Archæan, dating from Archæan time, was the first indication of a future St. Lawrence channel. It continued to be an arm of the sea, or deep bay, through the Lower Silurian, and underwent a great amount of subsidence as it received the thick formations of that era. After the Lower Silurian era, marine strata ceased to form, indicating thereby that the sea had retired; and fresh waters, derived from the Archæan heights of

Canada and New York, probably began their flow along its upper portion, and emptied into the St. Lawrence Gulf of the time not far below Montreal.

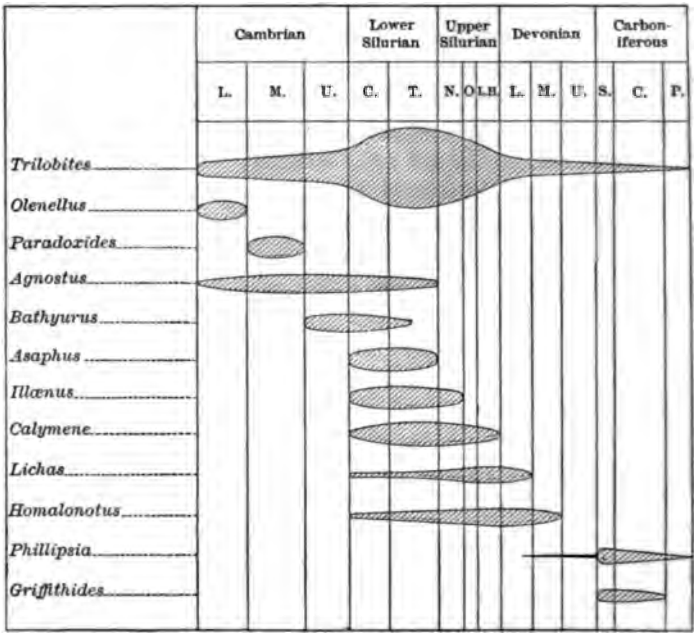
The Hudson-Champlain Valley apparently dates from Archæan time, and was a salt-water channel in the Lower Silurian. At the close of the Lower Silurian the channel was closed by the elevation of the region, but it was probably temporarily reopened in the Lower Helderberg period. The Hudson River must have commenced at the close of the Lower Silurian, as an insignificant stream, draining a part of the Adirondacks, and emptying into the Eastern Interior sea near Albany.

An embryo Mississippi River probably began early in Paleozoic time to drain the Archæan regions of Wisconsin and Minnesota. But the main part of the Mississippi and its tributaries, east and west, was not in existence in the Paleozoic ages. In the times of Carboniferous verdure, when the continent was in large part above the sea level, the Ohio and Mississippi basins were regions of great marshes, lakes, and bayous, and not of great rivers; for great rivers could not exist without high land to supply water and give it a flow.

Climate. — No evidence has been found through the Paleozoic records of any marked difference of temperature between the zones. In the Carboniferous era the Arctic seas had their Corals and Brachiopods, and the Arctic lands their forests and marshes under dense foliage, no less than those of America and Europe. The facts bearing on this subject are stated on page 312.

Life. — *Appearance and Disappearance of Species.* — With the beginning of each formation in the series, new species appeared, and the old ones more or less completely disappeared. Local changes in the life occurred in connection even with the minor transitions in the rock formations, as in the transition from a bed of shale to sandstone or to limestone, and the reverse. Thus, through the ages, life and death were in concurrent progress.

Beginning and Ending of Genera, Families, and Highe1 Groups. — The following table of the range of genera of Trilobites illustrates the progress which took place in this group, and exemplifies the general fact with regard to other groups: —



In the above table, the vertical columns correspon(to the eras and periods. The shaded area opposite th(name *Trilobites* shows that the group commenced in th(beginning of the Cambrian, attained its chief developmen in the Lower Silurian, then gradually declined, but con tinued till the Permian. Some genera are seen to hav(a very limited range in time, as ***Olenellus*** and ***Paradox ides***, confined respectively to the Lower and Middl(Cambrian; while ***Agnostus*** extends through the Cam brian and Lower Silurian, and *Homalonotus* through the Silurian and a large part of the Devonian.

In a similar manner the genera and families of Brachiopods began at different periods or epochs, and continued on for a time, to become, in general, extinct. Many genera ended in the course of the Paleozoic or at its close; only a few continued into later periods. The history of other groups illustrates the same law.

Special Peculiarities of Paleozoic Life. — The following facts show in what respects the life of the Paleozoic ages was peculiarly ancient: —

1. Not only are the species all extinct (with the possible exception of a few Diatoms of the Carboniferous, said to be identical with living species), but also the great majority of the genera.

2. Among Cœlenterates, the Anthozoans were largely of the tribe of Cyathophylloid corals, which is almost exclusively ancient or Paleozoic.

3. The Echinoderms were mostly Crinoids, and these were in great profusion. Crinoids were far less abundant, and of different genera, in the Mesozoic; and now very few species exist.

4. Among Molluscoids, Brachiopods were exceedingly abundant: their fossil shells far outweigh the fossils of any other group. But in the Mesozoic they were much less numerous; and at the present time the group is nearly extinct.

5. Among Mollusks, the Cephalopods were represented very largely by Orthocerata, but few species of which existed in the early Mesozoic, and none afterward.

6. Among Arthropods, Trilobites were the most common Crustaceans — a group exclusively Paleozoic.

7. Among Vertebrates, the Paleozoic Fishes were either Selachians, Placoderms, Ganoids, or Dipnoans. Of the Selachians, a large proportion were Cestracionts — a tribe common in the Mesozoic, but now nearly extinct. Nearly all the Ganoids had vertebrated tails. Compara-

[redacted]

tively few Ganoids with vertebrated tails lived after the Paleozoic, and the whole subclass is now nearly extinct. Of the Dipnoans, only four species now survive. The Amphibians all belonged to the order of Stegocephala — a group which became extinct early in the Mesozoic.

8. Among terrestrial Plants, there were Lepidodendrids, Sigillarids, Calamites in great profusion, making, with Conifers and Ferns, the forests and jungles of the Carboniferous and later Devonian: no species of *Lepidodendron* or *Calamites* is known after the Paleozoic, and only a single Triassic species of *Sigillaria.*

Thus, the Paleozoic or ancient aspect of the animal life was produced through the great predominance of Brachiopods, Crinoids, Cyathophylloid Corals, Orthocerata, Trilobites, Placoderms, vertebrate-tailed Ganoids, and Stegocephala; and that of the plants, through the Lepidodendrids, Sigillarids, and Calamites. In addition to this should be mentioned the absence of Angiosperms among Plants; the absence of Dibranchs among Cephalopods, Brachyurans among Crustaceans, the higher orders (those with complete metamorphosis) among Insects,[1] Teleost Fishes, all modern orders of Amphibia, all orders of Reptiles now existing except the nearly extinct Rhynchocephala, and the entire classes of Birds and Mammals.

Mesozoic and Modern Types begun in Paleozoic Time. — The principal Mesozoic type which began in the Paleozoic was the Reptilian. But besides these Reptiles there were the first of the Decapod Crustaceans; the first of the great group of Ammonites, the Goniatites being of this group; the first of Scorpions, Spiders, Centipeds, and Hexapod Insects. The type of Insects belongs eminently to modern time; for it probably has now its fullest display.

Thus, while the Paleozoic ages were progressing, and the types peculiar to them were passing through their

[1] With the exception of some Insects which were probably Neuropters, and possibly a few Beetles (Coleopters).

time of greatest expansion in numbers and complexity of structure, there were other types introduced which were to have their culmination in a future age.

DISTURBANCES CLOSING PALEOZOIC TIME.

General Quiet of the Paleozoic Ages. — The long ages of the Paleozoic passed with few considerable disturbances of the strata of eastern North America. There was, indeed, the elevation of the Taconic system of mountains at the close of the Lower Silurian, accompanied by the emergence of much of the Atlantic Border region; and again, at the close of the Devonian, there were minor disturbances and upturnings in eastern New Brunswick, part of Nova Scotia, and eastern Canada. Besides these changes, there was, through the ages, a gradual increase in the amount of dry land; and, through all the periods, over a large part of the continent, slow oscillations were in progress, varying the water level, and thus occasioning alternations in the kinds and extent of the deposits. But these movements of the earth's crust were exceedingly slow — probably less than a foot a century. There may have been many occasional quakings of the earth — perhaps even exceeding the heaviest of modern earthquakes. There may have been at times sudden risings or sinkings of portions of the continental crust. But the condition of the strata of the interior of the continent, and of the Appalachian region south of the Green Mountains, indicates that general quiet prevailed through the long Paleozoic ages. In Europe there are more frequent unconformabilities in the series of Paleozoic rocks, indicating that the progressive development of that continent was less simple and uniform than that of North America. But even in Europe the changes in the course of Paleozoic time were much less considerable than those near its close.

The Appalachian the Region of Greatest Change of Level. — The region of greatest movement during these ages was the Appalachian. For it has been shown that the oscillations which there took place resulted in subsidences of one or more thousand feet with nearly every period of the Paleozoic. In Pennsylvania and Virginia the subsidence continued through a large part of the Carboniferous age, until it amounted to about 30,000 feet. But this sinking was quiet in its progress, as is proved by the regularity in the series of strata.

The thickness of the coal beds indicates that the coal-plant marshes were long undisturbed, and therefore that long periods passed without appreciable movement.

The Post-Paleozoic, or Appalachian, Revolution.—This long time of comparative quiet was brought to a close by one of the most strongly marked periods of comparatively rapid change in the course of geological time. Mountains were made in various parts of the world, other great geographical changes took place, and the changes in the life of the globe were as strongly marked as those in geography. It was the close of one of the great æons in the world's history, and the beginning of another. Such an event is properly styled a revolution.

The Appalachian Range.—The most striking geographical change in eastern North America was the elevation of the Appalachian range. As that range has been taken as a type in the exposition of the theory of mountain-making (page 211), it is unnecessary here to give any detailed discussion. Attention has already been called to the progressive subsidence of the geosyncline, the accumulation of an enormous thickness of strata, the weakening of the deeply buried sediments by the internal heat of the earth, the final yielding to the accumulating strain, the formation of a series of approximately parallel, more or less unsymmetrical, folds, varied in parts of the range by faults of thousands of feet. The Appalachian range proper—a single orogenic individual—extends over a distance of 1000 miles, from New York to Alabama.

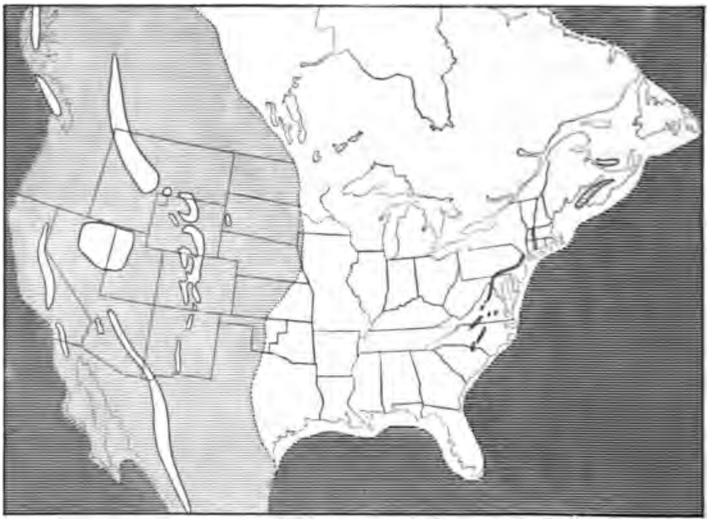
The Appalachian System.—The Appalachian range is only one of the ranges made at this time in eastern North America. There was another to the east, the Acadian range, extending from Newfoundland probably to Narragansett Bay in Rhode Island — a distance exceeding 800 miles (now partly submerged). In the metamorphic processes connected with the elevation of this range, much of the coal of Rhode Island actually passed beyond the anthracite stage, and was converted into graphite. A third range belonging to the Appalachian system is the Ouachita range in Arkansas and the Indian Territory. There is also evidence of post-Carboniferous disturbance in the beds of the Paleozoic trough extending from Gaspé, Canada, to Worcester, Massachusetts. The upturning and metamorphism of the Devonian rocks in the Connecticut Valley may belong to the same date. In western North America, some orogenic movements in the Great Basin are believed to date from this time.

Disturbances in Foreign Countries. — In the north of England, and also in the region of the South Wales Coal field, extensive disturbances took place between the Carboniferous and the Permian period. Murchison states that the close of the Carboniferous period was specially marked by disturbances and uplifts; that it was then "that the coal strata and their antecedent formations were very generally broken up, and thrown, by grand upheavals, into separate basins, which were fractured by numberless powerful dislocations."

It is noteworthy that these disturbances in England were not precisely contemporaneous with the Appalachian revolution in eastern North America, the latter occurring after the Permian. Devonian and Carboniferous rocks were subject to pre-Permian dislocations also over a large region of western Europe from Brittany to Bohemia, and from Ardennes to the Vosges and the Black Forest. Carboniferous rocks are folded in the Urals, giving evidence of orogenic movements of post-Carboniferous date, though the backbone of the Urals is Archæan. Some disturbance also took place in the Alps about the close of Paleozoic time, though the elevation of the Alps is chiefly due to movements of much later date.

North American Geography after the Appalachian Revolution. — The accompanying map shows approximately the condition of North America after the Appalachian revolution. Substantially the whole eastern half of the continent

FIG. 389.



Map of North America after the Appalachian Revolution.

had become dry land, the shore of the Continental sea corresponding roughly with the meridian of 97° W. Since no marine strata of early Mesozoic age are known anywhere along the Atlantic or the Gulf border, it is probable that the shore line was then even outside of its present position. In the map, the shore line is drawn where the 100-fathom curve lies at present. It is possible, however, that borings through the Tertiary and Cretaceous formations of the Atlantic and Gulf border may reveal the existence of early Mesozoic strata of which no evidence has yet been discovered. West of the meridian of 97°, the American continent was represented only by islands whose shore lines cannot be as yet exactly located.

Geographical Changes in the Region of the Indian Ocean. — The Permian flora of South Africa, India, and Australia is so nearly identical as to require the assumption of land connection between those regions. The hypothesis has been generally adopted, that a land area of which Madagascar, the Mascarene, Seychelle, and other islands in the Indian Ocean are remnants, connected South Africa with India. This hypothetical area Suess has named *Gondwána-land*, from the local name of a series of Permian and Triassic strata in India. Some eminent geologists suppose this land area to have extended across the Indian Ocean to Australia; but that extension is rendered improbable by the great depth of the Indian Ocean. Whatever connection existed between Africa and Australia is better explained by the hypothesis of a northward extension of the Antarctic continent. Such an extension of Antarctic land may possibly account for the glacial conditions indicated by some of the Permian conglomerates in those regions (page 299). Gondwána-land, in the more restricted sense of a land area between Africa and India, is supposed to have persisted until the Tertiary era, when it subsided, leaving the islands in the western part of the Indian Ocean as its monuments. Recent discoveries indicate the occurrence of substantially the same Permian flora in South America, in southern Brazil, and in Argentina. This fact also may find explanation in the hypothesis of northward extensions of the Antarctic Continent.

Change of Fauna and Flora. — With perhaps the exception of a few Diatoms, no Paleozoic species is known to have survived into Mesozoic and later times. Many species doubtless were exterminated. Others underwent variation and adaptation, so that the remains of their modified descendants, when recognized in later strata, are classified as distinct species. It cannot be affirmed that the extermination (or even the change in species) was universal; for the strata accessible to study, as they are confined to portions of the continental seas, testify only as to changes and destructions in those seas, and not respecting the life existing elsewhere. The causes of so great a change in fauna and flora are only imperfectly understood. The gradual cooling of the sun, the progressive removal of water and carbon dioxide from the atmosphere, and the climatic changes resulting directly and indirectly from geographical changes, must have profoundly affected the conditions of life. Changes of land into sea or of sea into land must have wrought great changes in the life of extensive regions. Earthquake waves and other local catastrophes may have wrought widespread devastation. (See page 458 for fuller discussion of causes of change in fauna and flora.) And it must be remembered that unconformability always means the loss, for the particular area, of the record of an interval in which migrations and other biological changes may have been in progress.

III. MESOZOIC TIME.

Mesozoic, or mediæval, time, in Geological history, is appropriately called the Reptilian Age. In the course of it the class of Reptiles passed its culmination — that is, its species increased in numbers, size, and diversity of forms, until they vastly exceeded in each of these respects the Reptiles of either earlier or later time. While the culmination of Reptiles is the most characteristic feature of the æon, it is also noteworthy as the time of culmination and incipient decline of Amphibians, Cephalopods, and Cycads; and of the commencement of Mammals, Birds, Teleost Fishes, and Angiosperms.

Area of Progress in Rock-making. — The area of rock-making in North America, during Mesozoic time, was somewhat different from what it was in Paleozoic. In *early* Paleozoic time, nearly the whole continent, outside of the northern Archæan area, was receiving its successive formations. By the close of Paleozoic time, substantially the whole continent east of the meridian of 97° had become dry land, as is shown by the absence of marine strata of later date. (See map, Fig. 339.) The areas of progress in Mesozoic time were (1) the *Atlantic Border*, (2) the *Gulf Border*, (3) the *Western Interior*, (4) the *Pacific Border*, and (5) the *Arctic Area*. In the early Mesozoic, only estuarine or fresh-water deposits were formed along the Atlantic Border, and no deposits now accessible along the Gulf Border; but in later Mesozoic time a subsidence of these border regions made them once more regions of marine sedimentation.

In Europe no analogous change can be distinguished; for the continent was, from the first, an archipelago, and it continued to bear this geographical character, though with an increasing prevalence of dry land, until the middle of Cenozoic time. At the beginning of Mesozoic time, western England stood as three or four islands above the sea (occupying approximately the area marked as covered by Paleozoic rocks on the map, page 295); and the area of future rock-making was mainly confined to the intervals between these islands and to the submerged area on the east and southeast. It is probable that this area and a portion of northeastern France were, geologically, part of a large North Sea basin.

Mesozoic time includes three eras.

1. **Triassic:** named from the Latin *tria*, three, in allusion to the fact that the rocks of the era in some parts of Germany consist of three separate groups of strata. This is a local subdivision, not characterizing the rocks in Great Britain or in most other parts of Europe.

2. **Jurassic:** named from the Jura Mountains, where rocks of the era occur.

3. **Cretaceous:** named from the Latin *creta*, chalk, the chalk beds of Great Britain and other regions in Europe and America being included in the Cretaceous formation.

I. TRIASSIC AND JURASSIC ERAS.

ROCKS: KINDS AND DISTRIBUTION.

In American Geology, it is convenient to treat these two eras together, since in several regions of the country it is impossible with certainty to distinguish the respective rock formations from each other.

In the Atlantic Border region these rocks occupy narrow troughs or basins parallel with the Appalachian chain, following its varying courses. The most northerly of these areas extends along the western border of Nova Scotia. A second occupies the valley of the Connecticut from northern Massachusetts to Middletown, Connecticut, and extends thence southwestward to New Haven on Long Island Sound, having a trend nearly parallel with the Green Mountains; it has a length of about 110 miles. Another — the longest — commences at the north extremity of the Palisades, on the west bank of the Hudson River, stretches southwestward through New Jersey and Pennsylvania (here bending much to the westward, like the Appalachians of the state), and reaches far into the State of Virginia. Another stretches — almost in the line of the last — across the southern boundary of Virginia into North Carolina, and another is comprised entirely within the limits of the latter state. The presence of the Triassic beneath the later formations has been detected in a boring for a well in one locality in South Carolina. The Triassic areas are indicated on the map on page 235 by an oblique lining in which the lines run from the left above to the right below.

The rocks are mainly sandstones and conglomerates, but include some considerable beds of shale, and in a few places impure limestone. The sandstones are generally red or brownish red. The freestone, or brownstone, of Portland, near Middletown in Connecticut, and of the vicinity of

Newark in New Jersey, is from this formation. The pebbles and sand of the beds were derived mainly from metamorphic rocks alongside of the regions in which they lie; and from some of the coarser layers large bowlders of granite, gneiss, and mica schist may be taken. The strata overlie directly, but unconformably, these metamorphic rocks. Some of the beds of shale are black and bituminous; and near Richmond, Virginia, and in North Carolina, there are valuable beds of bituminous coal.

The several ranges of this sandstone formation are remarkable for the great number of dikes and sheets of trap intersecting them. As the trap (diabase) is considerably harder than the stratified rocks, the dikes and sheets have generally formed more or less prominent ridges (hills of circumdenudation, page 133). Mount Holyoke in Massachusetts, East and West Rocks near New Haven in Connecticut, and the Palisades on the Hudson are a few examples of these trap ridges. Trap is an igneous rock — one that was ejected in a melted state from a deep-seated source, through fissures made by a fracturing of the earth's crust. The proofs that the trap came up through the fissures in a melted state are abundant; for the adjacent sandstones are often baked so as to be very hard, and sometimes filled with crystallizations, as of epidote, tourmaline, garnet, hematite, etc., evidently due to the heat.

Owing to the absence of marine fossils, it has been somewhat uncertain to what part of the Triassic or Jurassic era this formation along the Atlantic Border belongs. It is sometimes called the Jura-Trias, and sometimes the Newark formation. The character of the fossil plants and Vertebrates indicates that it is most probably Upper Triassic, corresponding to the Keuper and Rhætic of Europe.

The Jurassic is perhaps represented on the Atlantic Border by the lower part of the Potomac formation (page 364).

In the Western Interior region there is a sandstone formation in northern Texas, extending northeastward to the boundary of Kansas, and westward into New Mexico, containing much gypsum (and hence called the Gypsiferous formation), but barren of fossils, except an occasional fragment or trunk of fossil wood, which is regarded as Triassic. Triassic beds occupy extensive areas along the Colorado River and its tributaries, in Arizona, Utah, and Colorado. Triassic beds also occur in the Black Hills of Dakota, the Wasatch Mountains and the Sierra Nevada, and in the western ranges of the Great Basin. In a large part of the beds referred to the Triassic, fossils are scanty or wanting.

Jurassic rocks occur near the Black Hills of Dakota, at many localities along the summit region of the Rocky Mountains, and in the Sierra Nevada. Much of the Jurassic rock is calcareous, and in many localities fossiliferous. The Upper Jurassic of Colorado, Wyoming, and Montana includes the *Baptanodon* beds and the overlying *Atlantosaurus* beds. The former have afforded fossils of marine Invertebrates and aquatic Reptiles; the latter are fresh-water deposits, and have yielded rich remains of Reptiles and Mammals. The *Atlantosaurus* beds may possibly be of Lower Cretaceous age, representing the Wealden formation of England. The Jurassic rocks of the Sierra Nevada have been to a large extent metamorphosed into crystalline schists, whose quartz veins are the repositories of the gold.

In Europe, the *Triassic* rocks of eastern France and Germany, east and west of the Rhine, consist of (1) a thick sandstone, predominantly reddish, but very variable in color, and often mottled (*Bunter Sandstein*); (2) a fossiliferous limestone (*Muschelkalk*); (3) a formation consisting chiefly of reddish and mottled shale and sandstone (*Keuper*). The uppermost beds of the Triassic constitute the *Rhætic* formation, consisting of limestone and shale, and containing in places remains of a flora somewhat transitional between the Triassic and the Jurassic.

The Rhætic is considered by some geologists the lowest member of the Jurassic. In England, the Triassic formation (No. 6 on map, page 295) consists of reddish sandstone and shale; it is mostly confined to a region just east of the Paleozoic areas of Wales and northern England, and to an extension of this region westward to Liverpool Bay (or over the interval between those two Paleozoic areas) and up the west coast.

This formation, in Europe, contains in many places beds of salt, and is hence often called the Saliferous group. At Northwich in Cheshire, England, there are two beds of rock salt, 90 to 100 feet thick; and there are similar beds at Vic and Dieuze in Lorraine, and in Würtemberg.

In the eastern Alps, the Triassic shows a very different lithological character from that which it bears in other regions, the Upper, as well as the Middle, Triassic being represented chiefly by great deposits of limestone.

The *Jurassic* rocks of Great Britain are divided into two principal groups: —

1. The *Lias* (No. 7 on map of England, page 295), consisting of grayish compact limestone strata.

2. The *Oölite* (No. 8 on map, page 295), consisting mostly of whitish and grayish limestones, part of them oölitic (page 40). One stratum, near the middle of the series, is a coral-reef limestone, much like the reef rock of existing coral seas, though different in species of coral. Near the top of the series there are some local beds of fresh-water or terrestrial origin, in what is called the Purbeck group, and one of them on the island of Portland is named, significantly, the *Portland Dirt Bed*.

On the continent of Europe, the Jurassic rocks are generally divided into three parts commonly called in Germany, respectively, *Lias*, *Dogger*, and *Malm*.

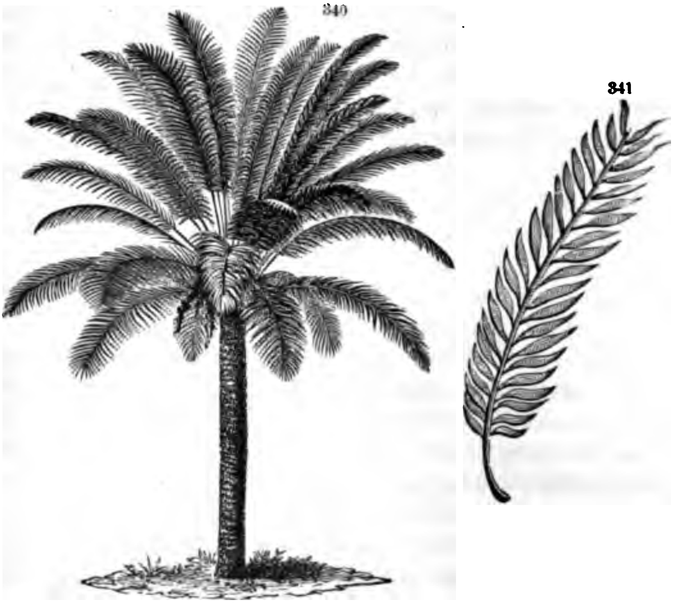
The Solenhofen lithographic limestone is a very fine-grained rock (thereby adapted for lithography), belonging near the top of the Upper Jurassic (*Malm*), occurring in the vicinity of Solenhofen and Eichstädt in Bavaria.

LIFE.

Plants.

The vegetation of the Triassic and Jurassic periods included numerous kinds of Ferns, both large and small, Equiseta, and Conifers, and so far resembled that of the Carboniferous age. But there were no forests or jungles of Lepidodendrids and Sigillarids. Instead of these Carbo-

Figs. 340, 341.



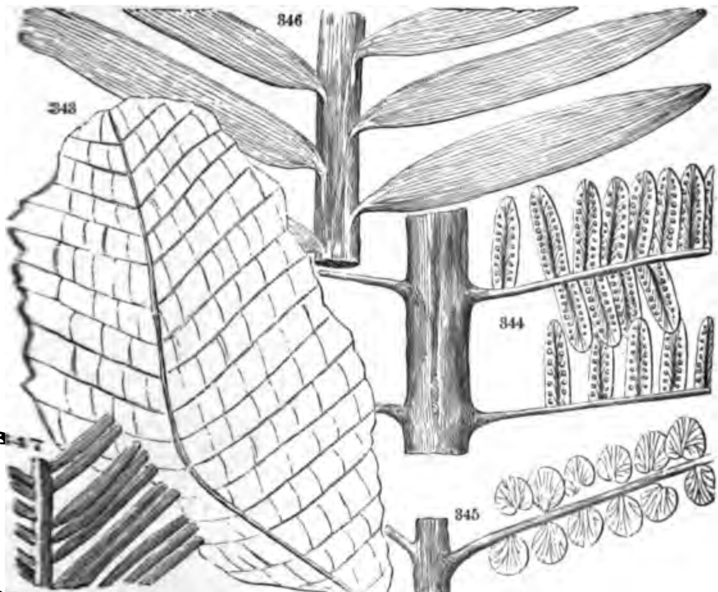
Cycads: Fig. 340, *Cycas circinalis*, × $\frac{1}{60}$; 341, leaf of *Zamia*, × $\frac{1}{6}$.

niferous types, a group of trees and shrubs sparingly represented in the Carboniferous, that of the Cycads, was eminently characteristic of the Mesozoic world. This group has now but few living species, *Cycas* and *Zamia* being the best-known genera. The plants have the aspect of Palms; and there was, therefore, in the Mesozoic forests a mingling of palmlike foliage with that of Conifers (Spruce, Cypress, and the like). But the Cycads are not Palms. They are Gymnosperms, resembling the Conifers both in the structure of the wood and in that of the extremely simple flowers. The resemblance to Palms is mainly in the cluster of great leaves at the summit, and the appearance of the exterior of the trunk. Fig. 340 represents, much reduced, a modern *Cycas*, and Fig. 341 the leaf of a living *Zamia*, one twentieth the actual length. The fossil remains of Cycads are either their

FIG. 342.

CYCAD: Stump of Mantellia megalophylla, × $\frac{1}{16}$.

FIGS. 343–347.



FERNS: Fig. 343, Clathropteris rectiuscula; 344, Oligocarpia robustior (in fruit); 345, Acrostichites linnæfolius. — CYCADS: Fig. 346, Podozamites Emmonsi; 347, Pterophyllum Riegeri.

trunks or leaves. A fossil species from the Portland Dirt Bed is represented in Fig. 342. The trunks of some Cycads have a height of 15 or 20 feet. In one respect some Cycads resemble the Ferns, — that is, in the unfolding of the young leaf, — the leaf being at first rolled up into a coil, and gradually unrolling as it expands.

Fossil plants are common in the coal regions of Richmond, Virginia, and North Carolina, and occur also in other localities. Figs. 343 to 345 represent a few of the Ferns: Fig. 343, a *Clathropteris*, from Easthampton, Massachusetts; Fig. 344, an *Oligocarpia*, from Richmond, Virginia, and the Trias of Europe; Fig. 345, an *Acrostichites*, from Richmond, Virginia. Figs. 346 and 347 are parts of leaves of two species of Cycad, from North Carolina. Large cones of Conifers have also been found. Several of the American plants are identical in species with those of the European Triassic, and a few are akin to European Jurassic forms.

Animals — American.

The American beds of the Atlantic Border region are remarkable for the absence of marine life: all the species appear to be either those of brackish water, or of fresh water, or of the land.

Invertebrates. — In the beds of the Atlantic Border, Sponges, Cœlenterates, Echinoderms, and Molluscoids are unknown; and the remains of Mollusks are of doubtful character. The Jurassic beds of the West contain many species of marine Invertebrates, and the Triassic a few.

The shells of Ostracoid Crustaceans are common in New Jersey, Pennsylvania, Virginia, and North Carolina, but have not yet been found in New England. Fig. 348 represents one of the little shells of these bivalve species, called *Estheria*. It was long supposed to be Molluscan. The Estheriæ are brackish-water species.

A few remains of Insects have been found, and probably, what is more remarkable, the tracks of several species.

These tracks were made on the soft mud, probably by the larvæ of the Insects, for many Insects pass their larval state in the water. Fig. 349 represents one of these larvæ found in shale at Turners Falls, Massachusetts; it resembles, according to Dr. Le Conte, the larva of a modern *Ephemera*, or May-fly. Figs. 350 and 351 are the tracks of Insects. Professor Hitchcock named nearly 30 species of tracks supposed to be those of Insects and Crustaceans.

Fig. 348.

Ostracoid: Estheria ovata.

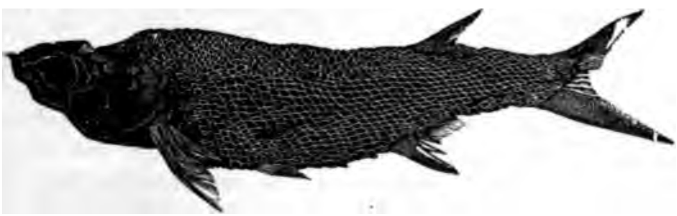
Vertebrate.—There are evidences of the existence of Fishes, Amphibians, Reptiles, Birds, and Mammals. With the appearance of the last two types, the subkingdom of Vertebrates was finally represented in all its classes.

Figs. 349–351.

Insects: Fig. 349, Mormolucoides articulatus; 350, 351, tracks of Insects.

1. *Fishes*. — The Fishes found in the American rocks include only Ganoids and a few Dipnoans, although Selachian remains are common in Europe. Fig. 352 represents one of the Ganoids, reduced one half. In this, as in most Mesozoic and

Fig. 352.



Ganoid: Catopterus gracilis, × ½; *a*, scale of same, natural size.

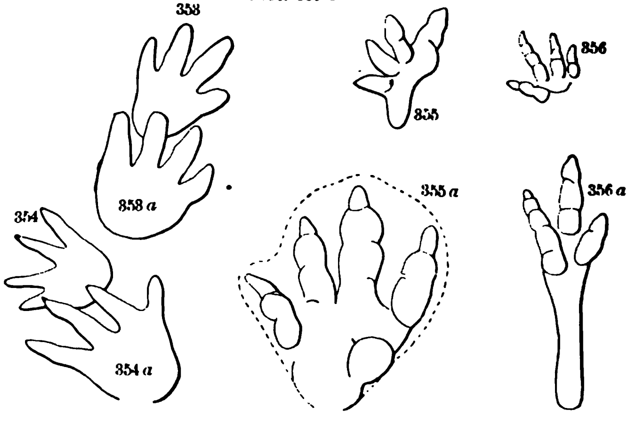
modern Ganoids, the tail is but slightly vertebrated, being nearly homocercal.

2. *Amphibians*, of the order of Stegocephala, or Labyrinthodonts (page 307), appear to have reached their

greatest size and numbers in the Triassic era. A foreign species is mentioned on page 351. Footprints in the Connecticut Valley beds appear to indicate the existence of American species. Figs. 353, 353 *a*, and 354, 354 *a*, represent tracks of two of these. It is not, however, possible in all cases to distinguish the tracks of Amphibians from those of Reptiles.

3. *Reptiles.* — The most important Reptilian remains in the American Triassic and Jurassic belong to the orders of Crocodilians and Dinosaurs, though most of the

FIGS. 353–356.



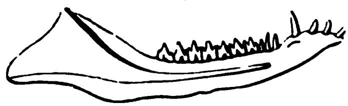
AMPHIBIANS: FIGS. 353, 353 *a*, tracks of Anisichnns Deweyanus, × $\frac{1}{3}$; 354, 354 *a*, Anisichnus gracilis, × $\frac{1}{3}$. — REPTILES: FIGS. 355, 355 *a*, Otozoum Moodii, × $\frac{1}{16}$: 356, 356 *a*, Anomœpus scambus. In each case the tracks of the hind foot are marked *a*.

other orders known from European specimens were also more or less abundantly represented in the American rocks. The Dinosaurs were so named from the Greek δεινός, terrible, and σαῦρος, lizard, some species being of gigantic size (though others were small animals, even less than two feet in length). In eastern North America, they are known by the thousands of footprints left by them in the Connecticut Valley and New Jersey, and a few portions of skeletons from Connecticut, Pennsylvania, and North Carolina; and in the West, by the huge skelewith important differences in the pelvis), but their jaws were toothed to the extremity. Fig. 359 represents one of the Triassic Theropods.

4. *Birds.* — A portion of a skull supposed to be that of a Bird has been found in the Atlantosaurus beds of Wyoming.

5. *Mammals.* — In the North Carolina Triassic have been found two jawbones (one of which is represented in Fig. 363), representing two small species of Mammals, perhaps Marsupials, but more probably Monotremes. The former of these groups is now represented by the Opossums in America and the Kangaroos and many other forms in Australia. The Monotremes (now represented by only two genera in Australia and the adjacent islands) are the lowest of all Mammals, being oviparous, and resembling Reptiles in many features of their anatomy. Several other Mammals, probably all Marsupials and Monotremes, have been described by Marsh from Jurassic beds in Wyoming and Colorado.

Fig. 363.



Mammal: Jaw of Dromatherium sylvestre, × 2.

The facts prove that the land population of Mesozoic America included Insects, Amphibians, Reptiles, Birds, and Mammals; and that the forests which covered the hills were mainly composed of Conifers and Cycads.

Animals — Foreign.

The European rocks of these periods, especially of the Jurassic, abound in marine fossils, and afford a good idea of the Mesozoic life of the ocean. The remains of terrestrial life are also of great interest, Mammals and an immense variety of Reptiles occurring in both the Triassic and the Jurassic beds, and Birds in the Jurassic.

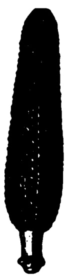
Cœlenterates. — Corals are common in some Jurassic strata; they are related to the modern types of corals, and not to the ancient. Fig. 364 represents one of the Oölitic species.

Echinoderms. — Crinoids are of many kinds; yet their number, as compared with other fossils, is far less than in the preceding ages; and they are accompanied by various new forms of Starfishes and Echinoids (page 69). Fig. 365 represents one of the Triassic Crinoids, the Lily Encrinite, or ***Encrinus liliiformis;*** Fig. 366, an Echinoid from the Oölite, stripped of its spines; and Fig. 367, one of the spines.

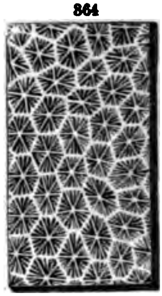
FIGS. 364–367.

365

367



364



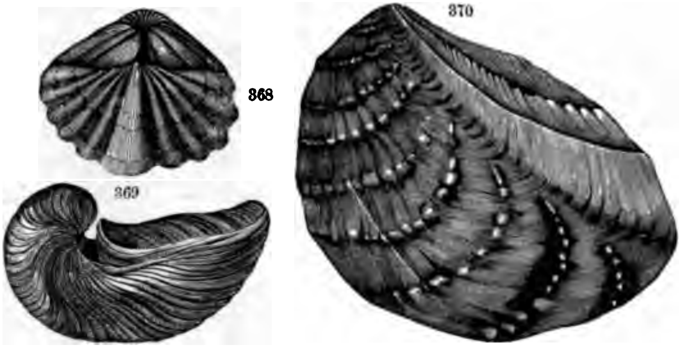
366

ANTHOZOAN: Fig. 364, Isastræa oblonga. — CRINOID: Fig. 365, Encrinus liliiformis. — ECHINOID: Fig. 366, Cidaris Blumenbachii (with spines removed); 367, spine of same.

Molluscoids. — Brachiopods are few compared with their number in the Paleozoic. The last species of the Paleozoic families *Spiriferidæ* and *Strophomenidæ* lived in the early part of the Jurassic period. Fig. 368 represents one of these last of the Spirifer group.

Mollusks. — Lamellibranchs and Gastropods abound in species, and under various new, and many of them modern, genera. Species of the genus *Gryphæa* were common in the Lias and later Mesozoic rocks; they are related to the Oyster, but have the beak incurved. Fig. 369 represents a Liassic species. *Trigonia* (Fig. 370) is a characteristic genus of the Mesozoic; the name alludes to the triangular form of the shell: the species figured is from the Oölite. The genus commenced in the Lias, and still survives in the Australian seas.

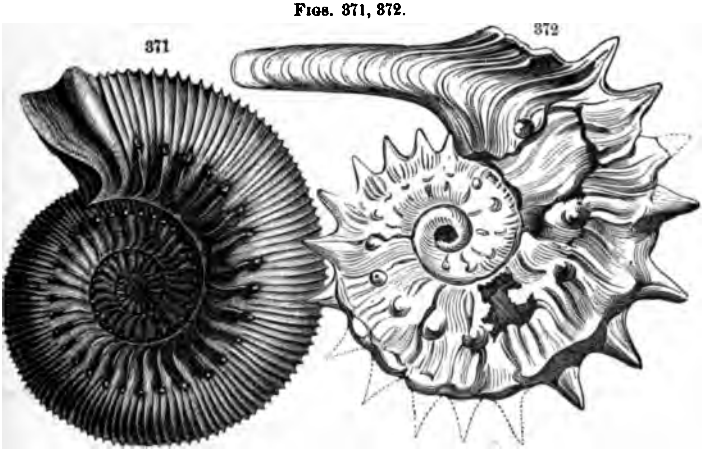
FIGS. 368–370.



BRACHIOPOD: Fig. 368, Spiriferina Walcotti. — LAMELLIBRANCHS: Fig. 369, Gryphæa incurva; 370, Trigonia clavellata.

But the most remarkable and characteristic of all Mesozoic Mollusks were the Cephalopods. This class passed its maximum as to number and size in the Mesozoic, and hundreds of species existed. The last of the

FIGS. 371, 372.



CEPHALOPODS: Fig. 371, Stephanoceras Humphriesianum; 372, Cosmoceras Jason.

Paleozoic type of Orthocerata lived in the Triassic era. In the same era, species of Ammonites, one of the most characteristic of Mesozoic groups, became common; and the new order of Dibranchs made its first appearance, being represented by genera of the Belemnite family, though the genus *Belemnites* did not appear until the Lias.

The Ammonites belonged to the order of Tetrabranchs, and had external chambered shells like the Orthocerata, Nautili (Fig. 110, page 75), and Goniatites. Two Oölitic species are represented in Figs. 371, 372. One of them (Fig. 372) has the side of the aperture very much prolonged; but the outer margin of the shell, whether prolonged or not, is seldom well preserved. The partitions (or septa) within the shells of Ammonites are bent back in many folds (and much plaited within each fold) at their junction with the shell, so as to make deep plaited pockets. A front view of the outer septum, with the entrances to its side pockets, is shown in Fig. 373. Fig. 416 *b*, page 371, illustrates the complex form of the junction of the edge of the septum with the shell (suture) in some species of Ammonites. The suture is also shown in Fig. 419. The Paleozoic Goniatites belonged to the Ammonite group, but the pockets were much more simple than in the typical Ammonites, the flexures of the margins of the partitions being without plications.

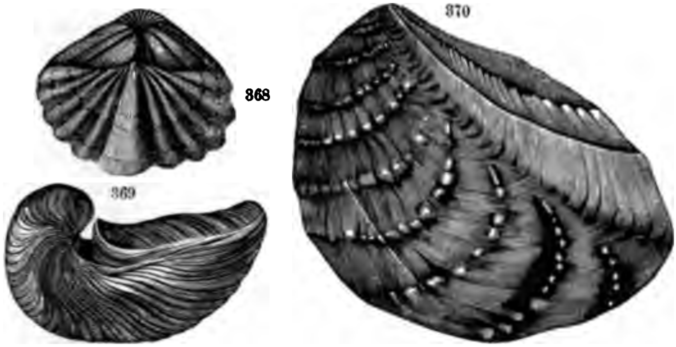
Fig. 373.

Cephalopod: Cladiscites tornatus.

The fossil Belemnite is an internal shell, analogous to the pen or bone (osselet) of a *Sepia*, or Cuttlefish (see Fig. 378). The part of the shell most commonly preserved is a conical or club-shaped body, shown in Figs. 375, 376, solid, except at its upper (anterior) end, which incloses a conical cavity. This cavity is occupied by a structure much resembling the chambered shell of an *Orthoceras*, whose upper (anterior) extremity is ex-

to the triangular form of the shell: the species figured is from the Oölite. The genus commenced in the Lias, and still survives in the Australian seas.

FIGS. 368–370.



BRACHIOPOD: Fig. 368, Spiriferina Walcotti. — LAMELLIBRANCHS: Fig. 369, Gryphæa incurva; 370, Trigonia clavellata.

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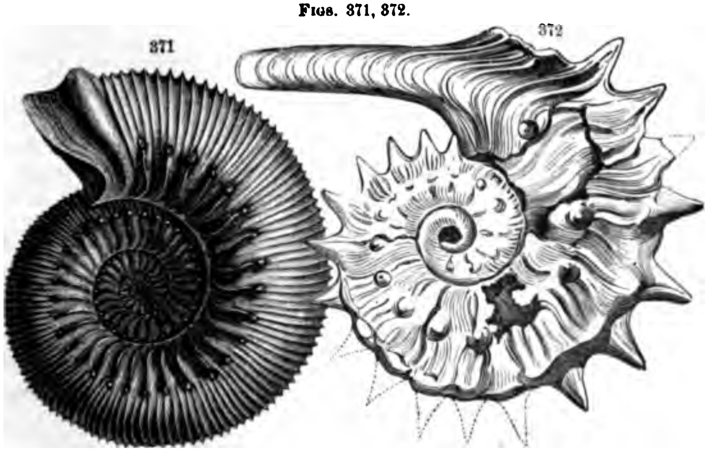

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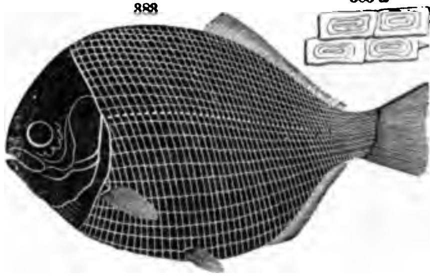
of grinding teeth (Figs. 129–131, page 82), still continued, and was represented by numerous species. There were also, in the Jurassic, Sharks with sharp-edged teeth, like most of those inhabiting modern seas. Most of the Ganoids were of modern type in having the tail nearly or quite homocercal, as shown in Fig. 383. One genus of Dipnoans, *Ceratodus*, occurring in both the Triassic and the Jurassic, is still represented by two living species in Australia. The discovery and dissection of the living *Ceratodus* in Australia first revealed the Dipnoan nature of the remarkable teeth which had long been known as Triassic fossils. It thus became known that Dipnoans were abundant in both Meso-

Fig. 383.

383 383 a



Ganoid: Fig. 383, Dapedius (restored), from the Lias, × $\frac{1}{6}$; 383 *a*, scales of same.

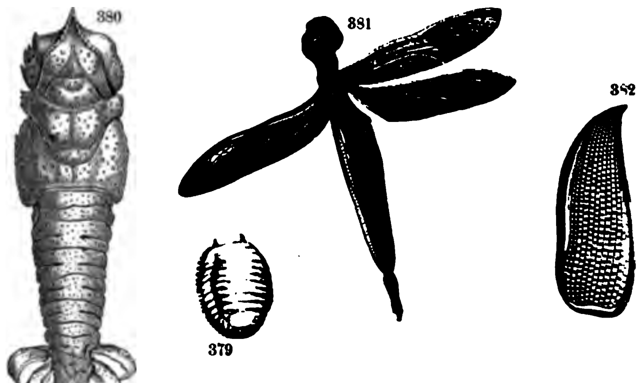
zoic and later Paleozoic time. Beside the ancient groups of Selachians, Ganoids, and Dipnoans, there were probably in the Jurassic, and even in the Triassic, representatives of the modern Bony Fishes, or Teleosts. These, however, did not become abundant until the Cretaceous.

Amphibians were common in the European Trias, as in the American, and some were of gigantic size. They all belonged to the order of Stegocephala, or Labyrinthodonts — an order which passed its culmination in the Triassic, and probably became extinct at the close of that era, though a single species has been doubtfully reported from the Jurassic.

One of these Triassic Labyrinthodonts had a skull over two feet long, of a form shown in Fig. 384; its mouth was set round with teeth three inches long (Fig. 385). The specimen here figured was found in Würtemberg. It is thing of the form of the animal, and also the ink bag in place.

Arthropods. — The Crustaceans were represented by species of rather modern aspect. Trilobites were entirely extinct. Tetradecapods were represented by species like the modern Sow-bugs (Fig. 379). Decapods included Macrurans, represented by numerous species of Shrimps and Crawfishes (Fig. 380 shows a Triassic species); and (in the Jurassic) Brachyurans, or Crabs. The presence of this highest suborder is a noteworthy step of progress.

FIGS. 379–382.



CRUSTACEANS: Fig. 379, Archæoniscus Brodiei; 380, Pemphix Sueurii. — INSECTS: Fig. 381, Libellula; 382, wing cover of Buprestis.

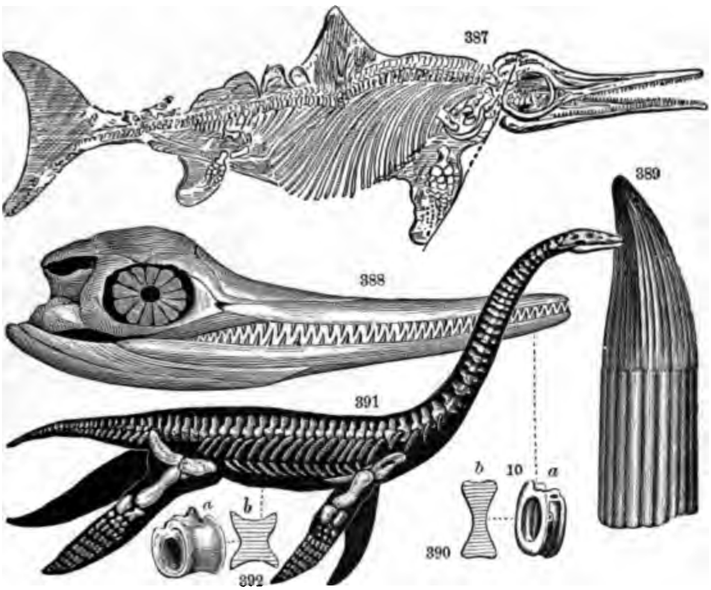
All but one of the important orders of Hexapod Insects were abundant in the Jurassic. Even the highest order, the Hymenopters (Bees, Ants, etc.), was well represented. Of the Lepidopters (Butterflies, Moths, etc.), only scanty remains have been discovered, whose reference to the order in question is more or less doubtful. Fig. 381 is a Dragon-fly from Solenhofen; and Fig. 382, the wing cover of a Beetle, from the Stonesfield Oölite.

Vertebrates. — The Fishes were chiefly Selachians, Ganoids, and Dipnoans. Among the Selachians, the ancient group of Cestracionts, characterized by a pavement

[redacted]

and large head, enormous eyes, and thin, doubly concave, and therefore fishlike, vertebræ. Their paddles were somewhat like the flippers of a Whale; but their great, vertically expanded, caudal fin, and the large dorsal fin, gave them an aspect more fishlike than that of Whales or of any other air-breathing Vertebrates. The name is from the Greek *ἰχθύς*, fish, and *σαῦρος*, lizard.

FIGS. 387–392.



REPTILES: Fig. 387, Ichthyosaurus quadriscissus; 388, head of Ichthyosaurus communis, × $\frac{1}{30}$; 389, tooth of same, natural size; 390 *a*, *b*, view and section of vertebra of same; 391, Plesiosaurus dolichodeirus, × $\frac{1}{30}$; 392 *a*, *b*, view and section of vertebra of same.

Fig. 388 represents the head of an Ichthyosaur, one thirtieth the natural size, showing the large eye and the numerous teeth. Fig. 390 *a* is one of the vertebræ, reduced, and Fig. 390 *b*, a transverse section of the same, exhibiting the fact that both surfaces are deeply concave, nearly as in fishes; Fig. 389 is one of the teeth, natural size. Some of the Ichthyosaurs were 30 or 40 feet long.

The Plesiosaurs, one of which is represented, very much reduced, in Fig. 391, had generally a long, snakelike neck, a comparatively short body, and a small head. Fig. 392 *a* represents one of the vertebræ, and 392 *b* a section of the same; it is doubly concave, but less so, and much longer, than in the Ichthyosaurs. Their limbs were paddles, but departed in general much less from the ordinary structure of a Reptilian foot than those of the Ichthyosaurs. Indeed, in some of the earlier and less specialized members of the order, the limbs still retained some adaptation for walking. Some species of Plesiosaur were 25 to 30 feet long. The Pliosaurs, which are included in the order of Plesiosaurs, though differing from the typical genus *Plesiosaurus* in having a larger head and a shorter neck, were 30 to 40 feet long. Remains of more than 70 species of Enaliosaurs have been found in the Jurassic rocks.

Besides these swimming Reptiles, there were numerous Crocodiles 10 to 50 feet long, and Dinosaurs, the bulkiest and highest in rank of all the class, 25 to 60 feet long.

The Dinosaurs, in Europe, as in America, included the herbivorous Sauropods, Ornithopods, and Stegosaurs, and the carnivorous Theropods. Among the Sauropods, a species of *Cetiosaurus* was 40 to 50 feet long. One of the best-known of the Theropods was the *Megalosaurus;* it was a terrestrial carnivorous Reptile about 30 feet in length. Strongly contrasted in size with the huge *Megalosaurus*, though belonging likewise to the Theropods, was the graceful, bird-like *Compsognathus*, not over two feet in length, from the lithographic limestone of Kelheim, Bavaria.

The Reptiles adapted for the air — that is, for flying — constitute the order Pterosaurs, so named from the Greek πτερόν, wing, and σαῦρος. The most common genus is called *Pterodactylus*. The general form of a Pterodactyl is shown in Fig. 393. The bones of one of the fingers are greatly elongated, for the purpose of supporting a fold of skin, so as to make it serve (like an analogous arrangement in Bats) for flying. The name *Pterodactylus* is from the Greek πτερόν, wing, and δάκτυλος, finger. The Jurassic Pterodactyls were mostly small, and probably had the habits of Bats; the largest was about the size of an Eagle.

FIG. 393.

PTEROSAUR: Pterodactylus spectabilis, natural size.

Other genera of Pterosaurs differed from *Pterodactylus* in having long tails. A restoration of one of these, showing the wing membranes and the rudder-like expansion of the tail, is given in Fig. 394. As Bats are flying Mammals, so the Pterosaurs are simply flying Reptiles, and have

Paleozoic type of Orthocerata lived in the Triassic era. In the same era, species of Ammonites, one of the most characteristic of Mesozoic groups, became common; and the new order of Dibranchs made its first appearance, being represented by genera of the Belemnite family, though the genus *Belemnites* did not appear until the Lias.

The Ammonites belonged to the order of Tetrabranchs, and had external chambered shells like the Orthocerata, Nautili (Fig. 110, page 75), and Goniatites. Two Oölitic species are represented in Figs. 371, 372. One of them (Fig. 372) has the side of the aperture very much prolonged; but the outer margin of the shell, whether prolonged or not, is seldom well preserved. The partitions (or septa) within the shells of Ammonites are bent back in many folds (and much plaited within each fold) at their junction with the shell, so as to make deep plaited pockets. A front view of the outer septum, with the entrances to its side pockets, is shown in Fig. 373. Fig. 416 *b*, page 371, illustrates the complex form of the junction of the edge of the septum with the shell (suture) in some species of Ammonites. The suture is also shown in Fig. 419. The Paleozoic Goniatites belonged to the Ammonite group, but the pockets were much more simple than in the typical Ammonites, the flexures of the margins of the partitions being without plications.

FIG. 373.

CEPHALOPOD: Cladiscites tornatus.

The fossil Belemnite is an internal shell, analogous to the pen or bone (osselet) of a *Sepia*, or Cuttlefish (see Fig. 378). The part of the shell most commonly preserved is a conical or club-shaped body, shown in Figs. 375, 376, solid, except at its upper (anterior) end, which incloses a conical cavity. This cavity is occupied by a structure much resembling the chambered shell of an *Orthoceras*, whose upper (anterior) extremity is ex-

[redacted]

he tail quills were arranged in a row either side of the ng tail.

Remains of Mammals occur in the Rhætic beds of Ger- ıny and England, in the Lower Oölite at Stonesfield, ıgland, and in the Middle Purbeck beds of the Upper

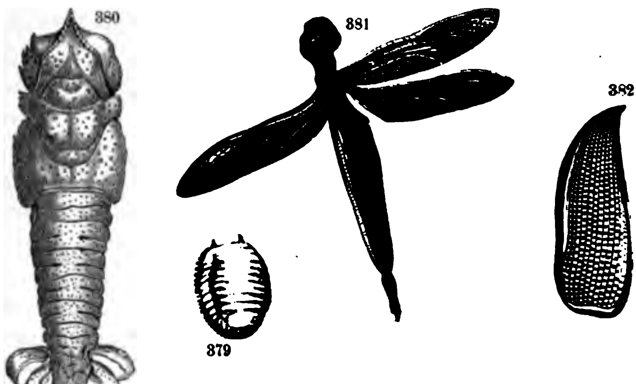
Fig. 395.

Bird: Archæopteryx macrura, × [illegible].

thing of the form of the animal, and also the ink bag in place.

Arthropods. — The Crustaceans were represented by species of rather modern aspect. Trilobites were entirely extinct. Tetradecapods were represented by species like the modern Sow-bugs (Fig. 379). Decapods included Macrurans, represented by numerous species of Shrimps and Crawfishes (Fig. 380 shows a Triassic species); and (in the Jurassic) Brachyurans, or Crabs. The presence of this highest suborder is a noteworthy step of progress.

FIGS. 379–382.



CRUSTACEANS: Fig. 379, Archæoniscus Brodiei; 380, Pemphix Sueurii. — INSECTS: Fig. 381, Libellula; 382, wing cover of Buprestis.

All but one of the important orders of Hexapod Insects were abundant in the Jurassic. Even the highest order, the Hymenopters (Bees, Ants, etc.), was well represented. Of the Lepidopters (Butterflies, Moths, etc.), only scanty remains have been discovered, whose reference to the order in question is more or less doubtful. Fig. 381 is a Dragonfly from Solenhofen; and Fig. 382, the wing cover of a Beetle, from the Stonesfield Oölite.

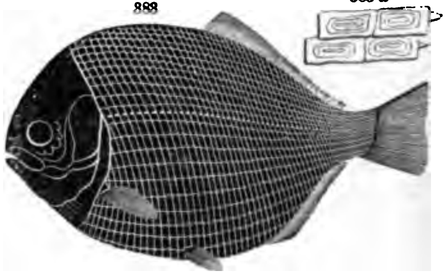
Vertebrates. — The Fishes were chiefly Selachians, Ganoids, and Dipnoans. Among the Selachians, the ancient group of Cestracionts, characterized by a pavement

[redacted]

of grinding teeth (Figs. 129–131, page 82), still continued, and was represented by numerous species. There were also, in the Jurassic, Sharks with sharp-edged teeth, like most of those inhabiting modern seas. Most of the Ganoids were of modern type in having the tail nearly or quite homocercal, as shown in Fig. 383. One genus of Dipnoans, *Ceratodus*, occurring in both the Triassic and the Jurassic, is still represented by two living species in Australia. The discovery and dissection of the living *Ceratodus* in Australia first revealed the Dipnoan nature of the remarkable teeth which had long been known as Triassic fossils. It thus became known that Dipnoans were abundant in both Mesozoic and later Paleozoic time. Beside the ancient groups of Selachians, Ganoids, and Dipnoans, there were probably in the Jurassic, and even in the Triassic, representatives of the modern Bony Fishes, or Teleosts. These, however, did not become abundant until the Cretaceous.

Fig. 383.

383 383 a



Ganoid: Fig. 383, Dapedius (restored), from the Lias, × ⅓; 383 a, scales of same.

Amphibians were common in the European Trias, as in the American, and some were of gigantic size. They all belonged to the order of Stegocephala, or Labyrinthodonts —an order which passed its culmination in the Triassic, and probably became extinct at the close of that era, though a single species has been doubtfully reported from the Jurassic.

One of these Triassic Labyrinthodonts had a skull over two feet long, of a form shown in Fig. 384; its mouth was set round with teeth three inches long (Fig. 385). The specimen here figured was found in Würtemberg. It is

The Plesiosaurs, one of which is represented, very much reduced, in Fig. 391, had generally a long, snakelike neck, a comparatively short body, and a small head. Fig. 392 *a* represents one of the vertebræ, and 392 *b* a section of the same; it is doubly concave, but less so, and much longer, than in the Ichthyosaurs. Their limbs were paddles, but departed in general much less from the ordinary structure of a Reptilian foot than those of the Ichthyosaurs. Indeed, in some of the earlier and less specialized members of the order, the limbs still retained some adaptation for walking. Some species of Plesiosaur were 25 to 30 feet long. The Pliosaurs, which are included in the order of Plesiosaurs, though differing from the typical genus *Plesiosaurus* in having a larger head and a shorter neck, were 30 to 40 feet long. Remains of more than 70 species of Enaliosaurs have been found in the Jurassic rocks.

Besides these swimming Reptiles, there were numerous Crocodiles 10 to 50 feet long, and Dinosaurs, the bulkiest and highest in rank of all the class, 25 to 60 feet long.

The Dinosaurs, in Europe, as in America, included the herbivorous Sauropods, Ornithopods, and Stegosaurs, and the carnivorous Theropods. Among the Sauropods, a species of *Cetiosaurus* was 40 to 50 feet long. One of the best-known of the Theropods was the *Megalosaurus;* it was a terrestrial carnivorous Reptile about 30 feet in length. Strongly contrasted in size with the huge *Megalosaurus*, though belonging likewise to the Theropods, was the graceful, bird-like *Compsognathus*, not over two feet in length, from the lithographic limestone of Kelheim, Bavaria.

The Reptiles adapted for the air — that is, for flying — constitute the order Pterosaurs, so named from the Greek πτερόν, wing, and σαῦρος. The most common genus is called *Pterodactylus*. The general form of a Pterodactyl is shown in Fig. 393. The bones of one of the fingers are greatly elongated, for the purpose of supporting a fold of skin, so as to make it serve (like an analogous arrange-

[redacted]

ment in Bats) for flying. The name *Pterodactylus* is from the Greek *πτερόν*, wing, and *δάκτυλος*, finger. The Jurassic Pterodactyls were mostly small, and probably had the habits of Bats; the largest was about the size of an Eagle.

FIG. 393.

PTEROSAUR: Pterodactylus spectabilis, natural size.

Other genera of Pterosaurs differed from *Pterodactylus* in having long tails. A restoration of one of these, showing the wing membranes and the rudder-like expansion of the tail, is given in Fig. 394. As Bats are flying Mammals, so the Pterosaurs are simply flying Reptiles, and have

[redacted]

little resemblance to Birds in structure, except that their bones are hollow, and adapted in form for the birdlike characteristic of flying.

Besides the kinds of Reptiles already mentioned, there were Turtles in both the Triassic and the Jurassic, and Lizards in the Jurassic; but, according to present knowledge, the world contained no Snakes.

Coprolites (or fossil excrements) of both Reptiles and Fishes are common in the bone beds. When cut and polished, they have a degree of beauty sufficient to give them some value in jewelry.

Fig. 394.

Pterosaur: Rhamphorhynchus phyllurus, × ⅛.

Remains of Birds have been found in the quarries of Solenhofen (page 335). They have revealed the fact that some of the Mesozoic Birds were reptilian in certain characters. The skeletons found (Fig. 395) show that these Birds had long reptile-like tails consisting of many vertebræ, and claws on the digits of the fore limb or wing, like those of the Pterodactyl and Bat, fitting them evidently for clinging. Moreover, the metacarpal bones were free, as in Reptiles, while in modern Birds they are immovably united. The mouth was provided with teeth. But, while thus reptilian in some points of structure, they were actually Birds, being feathered animals, and having the expanse of the wing made, not by an expanded membrane as in the Pterodactyl, but by long quill feathers.

The tail quills were arranged in a row either side of the long tail.

Remains of Mammals occur in the Rhætic beds of Germany and England, in the Lower Oölite at Stonesfield, England, and in the Middle Purbeck beds of the Upper

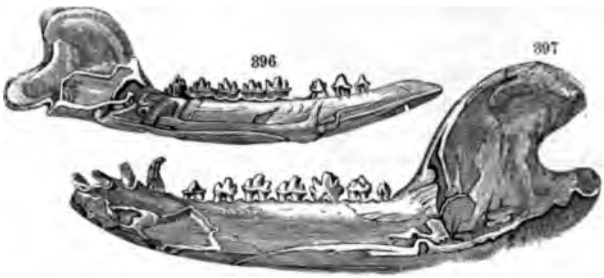
Fig. 395.

Bird: Archæopteryx macrura, × ⅓.

Oölite (page 335). About thirty species have been made out, more than twenty of them from relics in the Middle Purbeck. The larger part, if not all, are Marsupials and Monotremes. Figs. 396, 397 represent the jaws of two species from Stonesfield, twice the natural size.

The remarkable transitional forms between Reptiles and Birds, as illustrated by the Ornithopod Dinosaurs on the one hand and *Archæopteryx* on the other, are of course what

Figs. 396, 397.



Mammals: Fig. 396, Amphilestes Broderipi, × 2; 397, Phascolotherium Bucklandi, × 2.

would be expected in accordance with the theory of evolution. Probably all the Triassic Mammals are Monotremes, and all the Jurassic Mammals Monotremes and Marsupials. The theory of evolution would require the class of Mammals to commence with reptile-like forms, such as Monotremes. The remarkable mammal-like peculiarities of the skulls of the Permian and Triassic Theromorph Reptiles are very suggestive as to the ancestry of the Triassic Mammals.

GENERAL OBSERVATIONS.

American Geography. — The Triassic sandstones and shales of the Atlantic Border region are sedimentary beds; consequently, the long, narrow tracts of country in which they were formed were occupied, at the time, more or less completely by water.

The absence of marine fossils has been remarked upon as proving that this water was either brackish or fresh;

and hence the areas were estuaries or deep bays running far into the land.

There was probably an abundance of marine life in the ocean, if we may judge from its diversity on the other side of the Atlantic; but the seacoast of the era must have been farther east than at present, so that any marine deposits that were made are now submerged. The present sea border is shallow for a distance of 80 miles from the New Jersey coast, the depth of water at this distance being but 600 feet. (See map, page 13.)

The deposits contain, on many of the layers, footprints, ripple-marks, raindrop impressions, and other evidences that they were formed partly in shallow waters, and partly as sand flats, or emerging marshes and shores, over which Reptiles might have walked or waded. If, then, they are several thousands of feet thick, there must have been a progressive subsidence of the valleys in which the deposits were formed. It is hence apparent that oscillations of level, like those that characterized the Appalachian region before and during the Appalachian revolution, were in progress. Two effects of this subsidence occurred: (1) The sandstone beds were more or less faulted and tilted, those of the Connecticut Valley receiving a dip to the east or southeast, those of New Jersey and Pennsylvania to the northwest. (2) In the sinking of the valley, an increasing strain was produced in the earth's crystalline crust beneath, which finally became so great that the crust broke, fissures opened, and liquid rock came up.[1] The dikes and sheets of trap are this liquid rock solidified by cooling. The earth's crust along the

[1] In the opinion of the editor, most of the trap sheets of the Connecticut Valley and New Jersey were poured out as contemporaneous sheets (page 188) over the underlying strata, and subsequently covered by later deposits. According to this view, the eruption of the trap took place before the tilting and faulting which occurred at the close of the deposition. The trap masses of East and West Rock, near New Haven, and the great Palisade sheet of New Jersey, are certainly intrusive, but they probably date from about the same time as the contemporaneous sheets.

terranean region and that of northern Russia indicate that an appreciable difference of climate had already become established between northern and southern Europe. The evidence is not altogether conclusive.

DISTURBANCES CLOSING THE JURASSIC ERA.

After the Jurassic era, or near its close, the lofty range of the Sierra Nevada on the eastern boundary of California was made. To the same system belong apparently the Cascade Range and the Blue Mountains of Oregon. Some disturbances took place also in the region of the Coast Range of California and Oregon, though that region experienced a later movement of elevation at the close of the Miocene. The close of the Jurassic is probably also the time of making of the West Humbolt Range and some other ranges over the dry plateau between the Sierra Nevada and the Wasatch Range. Triassic and Jurassic fossils have been found in the rocks of the Sierra Nevada, while Cretaceous fossiliferous beds lie unconformably over the upturned strata of the mountains: the former fact proves that the mountain-making occurred after the Jurassic era; and the latter, that it took place before the Cretaceous.

II. CRETACEOUS ERA.

GENERAL CHARACTERISTICS.

The Cretaceous, the closing era of Mesozoic time, was also, in some respects, a transition era between the Mesozoic and Cenozoic. During its progress, as is explained beyond, occurred the decline, and, at its close, the extinction, of a large number of the tribes of the mediæval world; while, at the same time, there appeared in its course other tribes eminently characteristic of the modern world. Among the modernizing features, the most prominent are the Angiosperms among plants, and the Teleosts among *Fishes.* Of the Teleosts, indeed, some representatives probably appeared in the earlier Mesozoic; but it is not certain that the supposed Triassic and Jurassic Teleosts were not Ganoids. The Teleosts certainly first attained a considerable development in the Cretaceous.

The Angiosperms include nearly all the fruit trees of the world, and constitute by far the larger part of modern forests. The Conifers and Cycads, wherever they now occur near groves of Angiosperms, exhibit the contrast between the mediæval foliage and that of the present age. The Teleosts (page 83) embrace nearly all modern Fishes excepting those of the subclass of Selachians, or Sharks. Their prevalence was as great a change for the waters as the new tribes of plants for the land.

AMERICAN GEOGRAPHY: AREAS OF ROCK-MAKING.

The accompanying map, Fig. 398, shows the areas in North America which were submerged beneath salt water during the Cretaceous. The vertical lining indicates the parts that were submerged during the Lower Cretaceous; the horizontal lining, those that were submerged during the Upper Cretaceous; and the cross lining, the areas under water through the whole period. The scale of the map is too small for the indication of the fresh-water Cretaceous areas.

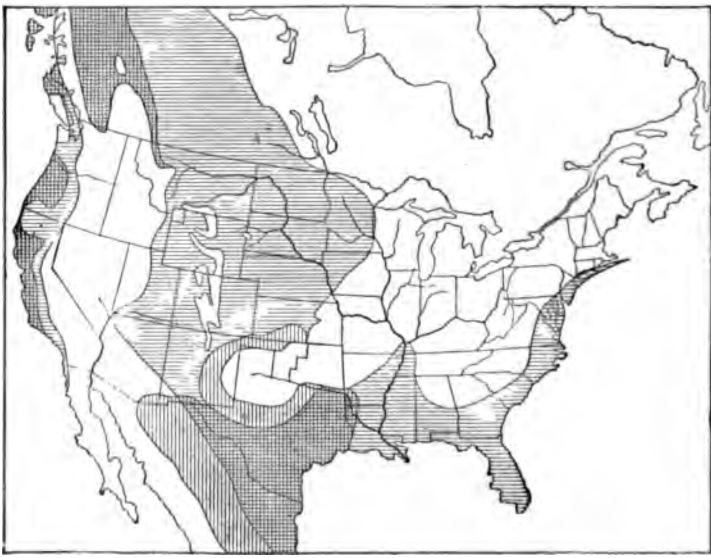
As shown by the map, rock-making was going on along the Atlantic Border, the Gulf Border, and the Pacific Border, as well as over the Western Interior (including the summit region of the Rocky Mountains). The Gulf Border may be considered as constituting two areas of rock-making — an eastern and a western, — since the deposits east of the Mississippi differ considerably from those of Texas and Mexico.

ROCKS: KINDS AND DISTRIBUTION.

Both in America and in Europe the Cretaceous formation is divided into two periods, — the LOWER CRETACEOUS and the UPPER CRETACEOUS.

A comparison of the map on this page with that on page 387 will show that the Cretaceous deposits along the Atlantic and Gulf Borders are to a very large extent concealed beneath the overlying Tertiary strata. In the Western Interior and along the Pacific Border, they constitute the surface rocks over large areas.

FIG. 398.



North America in the Cretaceous era.

The *Lower Cretaceous* is represented on the Atlantic Border by the fresh-water Potomac formation, including sandstones and shales and unconsolidated sands and clays, not exceeding 1200 feet in thickness, and exposed in a narrow and interrupted belt from Nantucket to South Carolina.[1] The presence of a few rare marine shells in

[1] It is possible that the lowest part of the Potomac formation (James River and Rappahannock stages) belongs to the Jurassic (see page 333), and that the uppermost part (Albirupian, or Raritan, stage) belongs to the Upper Cretaceous.

this fresh-water formation shows that the coast line could not have been far off. In the western Gulf Border the Lower Cretaceous formation (Comanche series) is mainly marine, and consists largely of limestone, a part of which is chalk. On the Rio Grande the formation attains a thickness of 5000 feet, though it is much less over most of the region. Fresh-water beds of the Lower Cretaceous, consisting of sandstones and shales, and containing some coal, appear in some parts of the Rocky Mountain region.

The *Upper Cretaceous* appears on the Atlantic Border, between the Tertiary of the coast and the older rocks of the interior, in a continuous area extending from New Jersey into Virginia, and in isolated patches farther north and south. The rocks are marine deposits about 500 feet in thickness, consisting of greensand alternating with beds of sand and clay. The greensand (locally called marl) consists of common sand mixed with blackish or olive-green grains of glauconite (a hydrous silicate of iron, alumina, and potash) formed by chemical changes at the bottom of the sea within the shells of Rhizopods. Along the Gulf Border marine Upper Cretaceous deposits were formed, consisting largely of limestone, especially in the western area, where much of the formation is chalk.

The Upper Cretaceous is immensely developed in the Western Interior region, the aggregate maximum thickness of the beds of the different epochs being over 15,000 feet. Four divisions are recognized, corresponding to the *Dakota*, *Colorado*, *Montana*, and *Laramie* epochs. Of these, the first and the last are fresh-water formations, the others marine. The rocks of the Colorado epoch are largely limestones, including much chalk. The deposits of the other epochs are mainly fragmental materials, including sandstones, shales, and conglomerates, with unconsolidated sands and clays. The Upper Cretaceous is the great coal formation of western North America, coal beds occurring at various horizons, but especially in the Laramie. The coal fields in Colorado alone have an area of about 18,000 square miles. Coal has been worked also in Utah, Wyoming, Montana, and New Mexico, and at various localities in British America. One bed at Evanston, Wyoming, is said to be 26 feet thick.

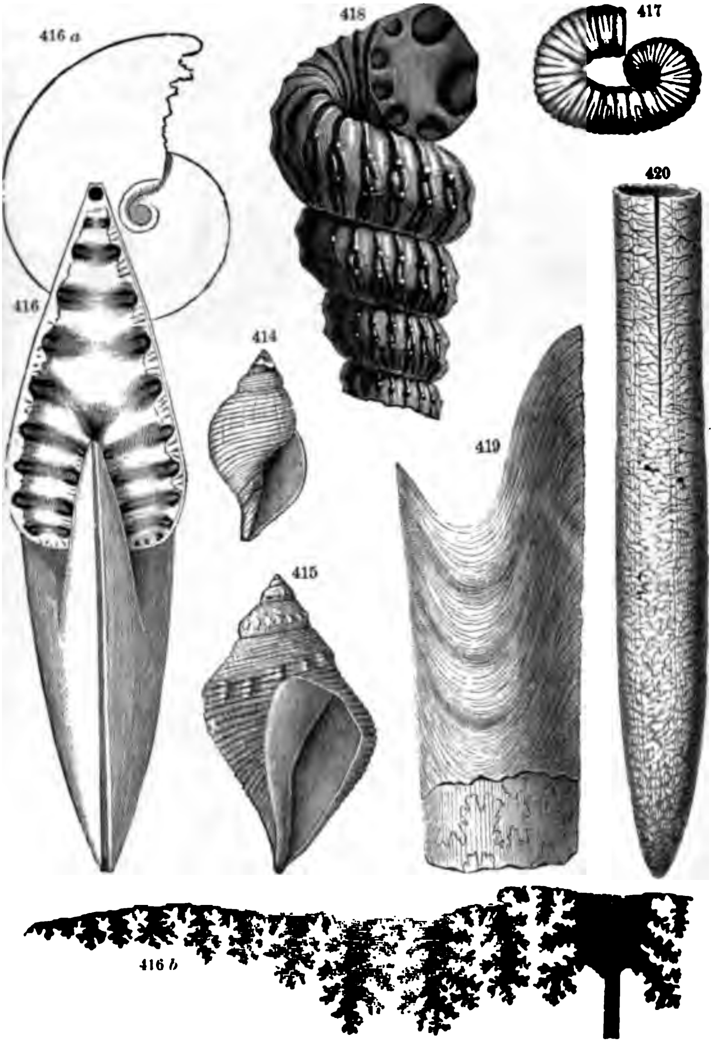
The Laramie beds represent the latest epoch of the Cretaceous, and show in their fossil flora a transition to the Tertiary. This epoch is not represented on the Pacific and the Eastern Gulf Border, and probably not on the Atlantic Border, the latest Cretaceous beds of those regions apparently belonging to the Montana epoch.

In Europe, as in North America, the Cretaceous formation constitutes the surface rocks in areas which form more or less interrupted borders of the Tertiary regions, or insular areas within those regions, indicating that the Cretaceous seas covered in general the areas now occupied by both Cretaceous and Tertiary rocks.

In England, the Cretaceous formation occupies most of the southeastern part of the country (9 and 10, on map, page 295). The Lower Cretaceous includes, as its basal member, the Wealden formation (9, on map), which is subdivided into the Hastings Sand and the Weald Clay. This is a fresh-water formation deposited in a great delta 20,000 square miles in area. The remainder of the Lower Cretaceous and the whole Upper Cretaceous consist of marine deposits, mostly greensand and chalk. Some of the chalk beds abound in concretions of flint, which consist largely of Diatoms, Sponge spicules, and other siliceous organisms. The Cretaceous formations of northern France, Belgium, western Germany, and Denmark much resemble those of England. Chalk appears also farther east, in southern Russia. In Saxony and Bohemia the Cretaceous rocks are mainly sandstones. In the Mediterranean region, where there is a great development of the Cretaceous, the rocks are mostly limestones, but do not include the chalk and greensand which are so characteristic of the northern Cretaceous region.

[redacted]

Figs. 414–420.



Gastropods: Fig. 414, Fasciolaria buccinoides; 415, Pyrifusus Newberryi. — Cephalopods: Fig. 416, Placenticeras placenta; 416 a, same, in profile, reduced; 416 b, diagram showing form of suture in same; 417, Scaphites larvæformis; 418, Turrilites catenatus; 419, Baculites ovatus; 420, Belemnitella Americana.

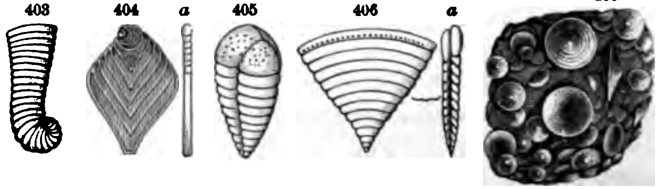
Cycads. The microscopic Algæ called Diatoms (page 88), which make siliceous shells, and others called Desmids, which consist of simple green cells without any skeleton, were very abundant. Both occur fossil in flint; and the Diatoms are believed to have contributed part of the silica of which the flint is formed.

Animals.

Protozoans. — The simplest of animals, Foraminifers, were of great geological importance in the Cretaceous period; for the Chalk is supposed to be made mostly of their minute calcareous shells. The powdered chalk is often found to contain large numbers of these shells, the great majority of which do not exceed a pin's head in size. A few of the forms are represented in Figs. 403–407, all very much enlarged, except Fig. 407, which is natural size. A very common kind resembles Fig. 50

Figs. 403–407.

403 404 a 405 406 a 407



Foraminifers: Fig. 403, Lituola nautiloidea; 404, Flabellina rugosa; 405, Chrysalidina gradata; 406, Cuneolina pavonia; 407, Patellina Texana.

(page 61), and is named *Rotalia*. Fig. 407 represents a large disk-shaped species from Texas.

Sponges. — Sponges were also very abundant, and their siliceous spicules (page 63) were another important source of the silica of the flints. The skeletons of some of the Sponges, both of the Cretaceous era and of modern time, in the deeper seas, consist wholly of silica. Fig. 408 represents a species whose skeleton was probably siliceous.

Cœlenterates. — Corals of modern type are not uncommon fossils.

Echinoderms. — Echinoids are abundant; and many of the Echinoids are of the highest division of the class, in which the radial arrangement of parts becomes largely subordinated to a bilateral symmetry. This group commenced in the previous era, but became more abundant in the Cretaceous.

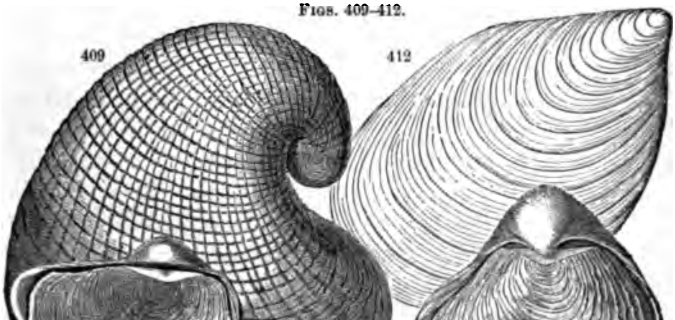
Fig. 408.

SPONGE: Siphonia lobata.

Mollusks. — Figs. 409–412 represent some of the most characteristic species of Lamellibranchs from the American Cretaceous. All these are of genera now extinct; but many genera both of Lamellibranchs and Gastropods that still survive were already in existence.

Fig. 413 represents one of the Rudista, a remarkable group of Lamellibranchs, peculiar to the Cretaceous, in

Figs. 409–412.



LAMELLIBRANCHS: Fig. 409, Exogyra costata; 410, Gryphæa vesicularis; 411, Gryphæa Pitcheri; 412, Inoceramus labiatus.

which the two valves of the shell are extremely unequal, the small left valve appearing as a sort of cover to the deep conical right valve.

Figs. 414, 415, represent two American species of Gastropods.

But the Cephalopods, in this era as in the preceding, were the most characteristic class of Mollusks. The Tetrabranchs were represented by numerous species of the Ammonite group, and the Dibranchs by Belemnites. Figs. 416–420 are Cephalopods, all American species except Fig. 418. Fig. 416 is a front view of a species of the Ammonite group, showing the pockets formed by the crumpling of the edge of the outer septum. Fig. 416 *b* shows the extremely complicated form of the suture in this species. Some of the Jurassic and Cretaceous Ammonites are 3 or 4 feet in diameter. Especially characteristic of the Cretaceous, though not unknown in previous eras, were genera of the Ammonite group in which the shell departed from the form of a closely coiled discoidal spiral (Fig. 371, page 347) which was typical in the group. Three of these aberrant forms are shown in Figs. 417–419. Fig. 417 is the loosely coiled *Scaphites;* Fig. 418, coiled in a turreted spiral, is a *Turrilites* (Latin *turris*, tower); Fig. 419 is the straight *Baculites* (Latin *baculum*, staff).

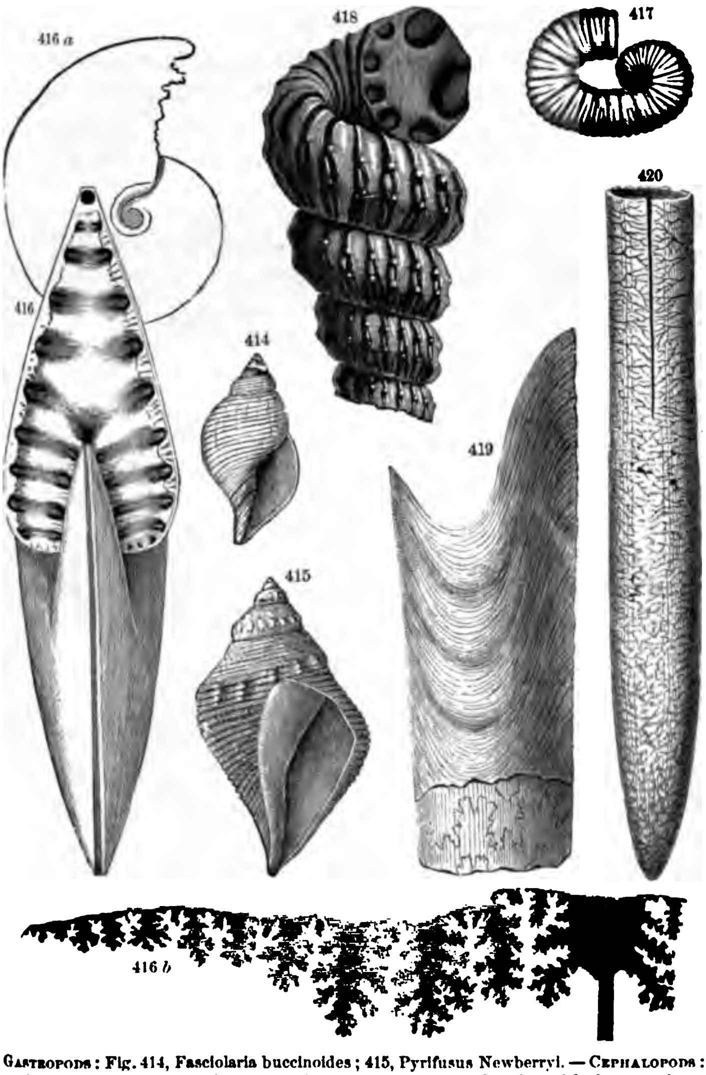
FIG. 413.

LAMELLIBRANCH: Hippurites Toucasianus.

Fig. 420 represents a species of Belemnite common in the Cretaceous beds of New Jersey.

Vertebrates. — There were great numbers of Teleosts, or Osseous Fishes, allied to the Herring, Salmon, Mackerel, etc. They occur along with numerous Sharks of both ancient and modern types, and also many Ganoids. Thus the ancient and modern forms of Fishes were associated in the population of the Cretaceous seas, the latter, however, greatly predominating, especially in the latter part

FIGS. 414–420.



GASTROPODS: Fig. 414, Fasciolaria buccinoides; 415, Pyrifusus Newberryi. — CEPHALOPODS: Fig. 416, Placenticeras placenta; 416 a, same, in profile, reduced; 416 b, diagram showing form of suture in same; 417, Scaphites larvæformis; 418, Turrilites catenatus; 419, Baculites ovatus; 420, Belemnitella Americana.

of the era. Fig. 421 represents one of these Teleost Fishes, related to the Salmon and Smelt.

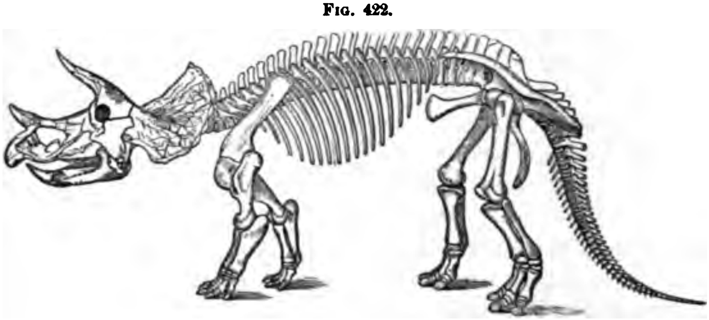
Reptiles included species of all the orders occurring in the Jurassic. The Plesiosaurs were represented by the

Fig. 421.

Teleost: Osmeroides Lewesiensis. × $\frac{1}{2}$.

genera *Cimoliosaurus*, *Elasmosaurus*, etc., some species of which were 50 feet in length. The Dinosaurs included species of all the groups represented in the Jurassic, though the Sauropods appear to have become extinct before the close of the Cretaceous. *Lælaps* is a well-known example

Fig. 422.

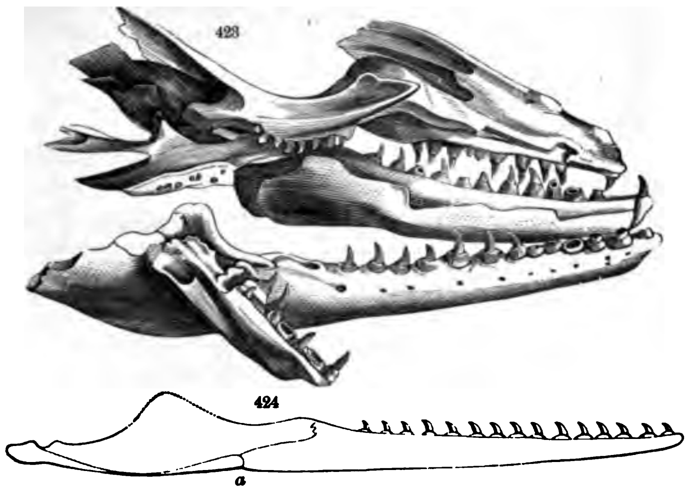


Dinosaur: Triceratops prorsus, × $\frac{1}{75}$.

of the Theropods, and *Iguanodon* and *Hadrosaurus* of the Ornithopods. Besides Ornithopods and Stegosaurs, the Predentata were represented by the remarkable Horned Dinosaurs, or *Ceratopsidæ* (Greek κέρας, horn, ὄψις, aspect), *peculiar* to the Laramie beds (Fig. 422). These resembled in many respects the Stegosaurs, but were strongly characterized by the great horn cores shown in the figure, which doubtless supported epidermic horns like those of cattle. Among the Pterosaurs, *Pteranodon* differed from the Jurassic genera (and from other Cretaceous genera) in being destitute of teeth. Two species from Kansas had a spread of wings of 20 to 25 feet.

There was also an order of Reptiles peculiar to the Cretaceous, that of the Mosasaurs, or Pythonomorphs: great

FIGS. 423, 424.



MOSASAURS: Fig. 423, Mosasaurus Camperi, × $\frac{1}{15}$; 424, lower jaw of Edestosaurus dispar, × $\frac{1}{8}$.

snakelike Reptiles, 15 to 75 feet long, swimming by means of four paddles — literally the Sea Serpents of the era. The remains of the head of one, from the banks of the river Meuse in Holland (whence the name), are represented in Fig. 423. The American rocks have afforded nearly fifty species of these Mosasaurs. The head of the largest was four feet long, and the mouth was of enormous size. Moreover, these Reptiles had a movable joint in the lower jaw, on either side, in place of the usual suture (at a, in Fig. 424), which enabled the two rami of a jaw (since the rami were not united at their extremities) to act like a pair of arms, in working down the immense throat any large animal they might undertake to swallow whole. A tooth of one of the Mosasaurs, half the natural size, is shown in Fig. 425.

Among the orders of Reptiles now living, there were numerous species of Crocodiles and Turtles; one of the latter, from Kansas, measuring 15 feet, according to Cope, between the tips of the extended flippers. There were also a few Lizards, and the earliest of Snakes.

The Birds of the Cretaceous were all apparently free from the reptilian characters of long tail and free metacarpals, possessed by the Jurassic *Archæopteryx;* but some of them, as first made known by Marsh, still retained teeth.

Fig. 425.

Tooth of Mosasaurus princeps, × ½.

Fig. 426, from Marsh, represents the skeleton of *Hesperornis regalis*, one eighth the natural size — a large Bird with rudimentary wings, flat sternum (as in the Ostriches), and teeth inserted in a groove. It resembled the Loons, or Divers, in several features of the skeleton, and was probably aquatic in habit. Fig. 432 represents a very different Bird, *Ichthyornis victor* — a Bird of moderate size, with well-developed wings, keeled sternum, teeth inserted in sockets, but with the very remarkable character of biconcave vertebræ. Both these Birds are from Kansas, but a Bird apparently allied to *Ichthyornis* has been found in the Greensand of England. Apparently there were other Cretaceous Birds which were toothless, and related to the modern Cormorants and Waders.

Mammals are represented by numerous teeth and frag-

[redacted]

FIGS. 426–431.

TOOTHED BIRD: Fig. 426, Hesperornis regalis, skeleton, × [illegible]; 427, lower jaw, × [illegible]; 428, tooth, × 4; 429, 430, vertebræ, × [illegible]; 431, pelvis, side view, × [illegible]; *il*, ilium; *is*, ischium; *p*, pubis; *a*, acetabulum.

ments of jaws, and a few fragments of other bones, from the Laramie beds of North America, and by a single tooth from the Wealden in England. They are probably all Monotremes and Marsupials.

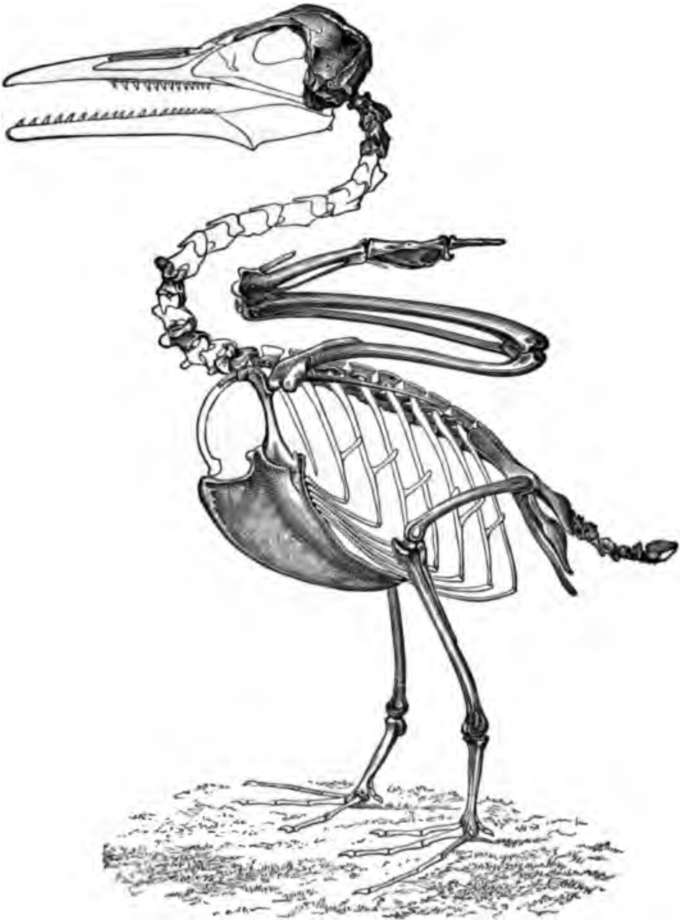
GENERAL OBSERVATIONS.

Geography. — The Cretaceous, both in North America and in Europe, as compared with the earlier periods of the Mesozoic, was eminently a period of submergence. This is indicated by the large areas occupied by marine formations; and especially by the large areas of chalk and other limestones. The deposits of chalk must have been formed, not in shallow waters adjacent to the shores, but in open seas. It is not probable, however, that the seas in which the chalk was deposited were of oceanic depth. Foraminifers are animals, not of the abyssal depths, but of the surface, the shells sinking to the bottom only after the death of the animals; and a foraminiferal deposit is therefore evidence of an open sea comparatively free from detritus, but not necessarily of great depth. The other fossils of the chalk belong apparently not to the abyssal fauna, but to that of comparatively shallow water.

As shown for North America by the map on page 364, the submergence did not attain its maximum until the earlier part of the Upper Cretaceous. The deposits of the Lower Cretaceous were largely of fresh-water origin, on both sides of the Atlantic.

On the Atlantic Border of North America, the strata of the Upper Cretaceous are the first marine deposits known since the Lower Silurian. The geanticlinal elevation formed at the time of the Taconic Revolution seems at last to have subsided. At the time of the greatest submergence, Chesapeake and Delaware bays were in the ocean; Florida was under water; the region of the Missouri River was a salt-water region; the Rocky Mountain region was largely submerged. This mountain region was in some parts at least 10,000 feet lower than now, the Cretaceous beds having this elevation upon it. The Mexican

Fig. 432.



Toothed Bird: Ichthyornis victor, × ½.

Gulf spread over the Gulf States from Florida to Texas, and extended northward to the mouth of the Ohio; while a vast mediterranean sea stretched from the western part of the Gulf of Mexico, northward over the great plains and the summit region of the Rocky Mountains, probably even to the Arctic Ocean — a distance of 3000 miles. About the middle of the Upper Cretaceous, there was a shallowing of the sea and an emergence of the land far north in British America, so that the great western mediterranean was cut off from the Arctic Ocean, and became a part of the Gulf of Mexico, though still having a length of 2000 miles or more. Gradually the area of this great western gulf contracted along its eastern border, and the depth diminished; until at last, in the Laramie epoch, brackish and fresh waters took the place of the seas in which chalk and other limestones had been deposited.

The Upper Cretaceous (and especially the Laramie epoch) was the great coal period of western North America, as the Carboniferous period was the coal period of eastern North America and western Europe. In each case, a large area which had been submerged beneath the sea was passing through an epoch of transition to terrestrial conditions. For a long time the area was balancing near the sea level, now emerging and clothing itself with luxuriant vegetation, now submerged and receiving sedimentary deposits. The kinds of plants which made the Cretaceous forests were, however, widely different from those of the Carboniferous.

Climate. — Although there is clearer indication of differentiation of zones of climate in the Cretaceous than in any earlier period, a warm climate still prevailed even in high northern latitudes. The Cycads of the Lower Cretaceous in Greenland indicate, according to Heer, a mean temperature not below 70° F. There appear to have been no true coral reefs in the British seas, though such reefs were certainly present in the Mediterranean basin. The isotherm of 68° for the coldest winter month apparently passed south, but not far south, of Great Britain. The plants of the upper Missouri region indicate a warm-temperate climate over that territory.

GENERAL OBSERVATIONS ON THE MESOZOIC.

Time Ratios. — The ratios between the Eopaleozoic, Upper Silurian, Devonian, and Carboniferous ages, as to the length of time that elapsed during their progress, or their time ratios, are stated on page 317 as probably not far from 6 : 1 : 2 : 2. By the same method, it follows that the ratio for the time of the Paleozoic and Mesozoic was nearly 4 : 1. That is, Mesozoic time was about one fourth as long as the Paleozoic; and the three eras of the Mesozoic were not far from equal, the Cretaceous being probably somewhat the longest.

American Geography. — On page 331 it is remarked that the Mesozoic formations were confined to the Atlantic, Pacific, and Gulf Border regions, the Arctic region, and an Interior region west of the Mississippi covering much of the Rocky Mountain area; and that the portion of the continent between that Interior region and the Atlantic Border had probably become part of the dry land. The facts which have been presented in the preceding pages have sustained this statement. The Triassic beds, as has been shown, lie in long, narrow strips between the Appalachians and the coast, and spread widely over the Rocky Mountain region and west nearly to the Pacific. The Jurassic beds have a similar wide distribution in the West, though probably wanting in the East. The Cretaceous beds cover the Atlantic and Gulf Borders, and a very large area over the slopes of the Rocky Mountains and the adjacent plains, and the Pacific Border west of the Sierra Nevada. The eastern half of the continent during the Mesozoic was, therefore, receiving rock formations only along its borders, while the western half had marine deposits in progress over its great interior and on the ocean's border.

The American Mesozoic deposits do not bear evidence that they were formed in a deep ocean. The Triassic and

Jurassic strata appear to have accumulated mainly along coasts, or in shallow waters off coasts, or in shallow estuaries or inland seas; some of the Cretaceous deposits indicate a clear and open sea, but not necessarily one of great depth.

The Appalachians — the eastern mountains of the continent — had been elevated before the early Mesozoic beds commenced to form (page 326). But the region of the Rocky Mountains — the western chain — was to a great extent still a shallow sea even during the Cretaceous era, or when Mesozoic time was drawing to its close (page 376).

One strongly marked epoch of mountain-making, in western North America, occurred at the close of the Jurassic, the Sierra Nevada and other high ranges dating from that time.

European Geography. — Europe has its Mesozoic rocks distributed in patches, or in several independent or nearly independent areas, which show that it retained its condition of an archipelago throughout Mesozoic time. The oscillations of level, as indicated by the variations in the rocks, — variations both as to the nature of the beds and their distribution, — were more numerous and irregular than in North America. The mountain elevations formed, however, were few and small compared with those that followed either the Paleozoic or the Mesozoic. One series of disturbances is referred to the close of the Triassic, and another to that of the Jurassic.

Among the Mesozoic formations of the European continent there are deposits of all kinds — those of seashores; of offshore shallow waters; of moderately deep, clear, and open seas; of inland seas; and of marshy, or dry and forest-covered, land.

Both in America and Europe there were some coal beds made, though all of them were comparatively insignificant, except those of western North America in the Upper Cretaceous; even these are inferior in extent to those of the Carboniferous.

Life. — The Mesozoic age witnessed — (1) the decline of some ancient or Paleozoic types of both plants and animals, (2) the increase and culmination of mediæval or Mesozoic types, and (3) the beginning of some of the most important of modern or Cenozoic types.

1. *Disappearance of Ancient or Paleozoic Features.* — Among the ancient tribes of plants, several genera of Ferns disappear in the Jurassic. Among the old Brachiopod tribes, the *Spirifer* and *Strophomena* families end in the Lias; among Mollusks, the Silurian type of *Orthoceras* has its last species in the Triassic; in the same era, the Ganoid Fishes mostly lose the vertebrated feature of their tails, characterizing them in the Paleozoic, and thus bear evidence of progress.

2. *Progress in Mesozoic Features.* — The Cycads, among plants, were those most characteristic of the Mesozoic: they afterward yielded to other kinds, and now are a nearly extinct group. The Cephalopods, among Mollusks, existed in vast numbers, both those with external shells (Tetrabranchs), as the Ammonites, and those without (Dibranchs), as the Belemnites. The whole number of species of the Ammonite group thus far described is almost 5000; and the vast majority of these belong to the Mesozoic, the Paleozoic genera of the group including comparatively few species. No Ammonite now exists, and the only Tetrabranch Cephalopods now living are six species of the genus *Nautilus*. The whole number of species of Cephalopods living in the course of Mesozoic time must have been many thousand, since only a part would have been preserved as fossils. The subkingdom of Mollusks, therefore, culminated in Mesozoic time; for its highest class, that of the Cephalopods, was then at its maximum.

The Stegocephala, or Labyrinthodonts, culminated in the Triassic, and became extinct at the close of that era (or possibly during the Jurassic).

The type of Reptiles was another that expanded and reached its culmination — that is, its maximum in number, variety, size, and rank of species,—and commenced its decline in Mesozoic time.

There were huge swimming Reptiles, fishlike Ichthyosaurs, and snakelike Mosasaurs, some of the latter 75 or 80 feet long, in the place of Whales in the sea; batlike Reptiles, or Pterodactyls, flying through the air; four-footed Reptiles, both grazing and carnivorous, many of them 25 to 50 feet long, occupying the marshes and estuaries, and great biped Reptiles, or Dinosaurs, over the land.

The Wealden formation of England has afforded remains of 30 or more species of Dinosaurs, Crocodiles, and Enaliosaurs, most of which were 10 to 50 feet long, besides Pterodactyls and Turtles; and many more than this must have lived, since not all that lived would have left their remains in the deposits. It is, however, not certain that all the species of the Wealden were contemporaneous. To appreciate this peculiarity of Mesozoic time, it should be considered that in the present age Great Britain has no large Reptiles. In the whole torrid zone (to which large Reptiles are now mostly restricted) there are not much more than a dozen species over 15 feet in length (Crocodiles, and Snakes of the Python and Boa families), and probably no species reaching a length of 30 feet. North America, during the Jurassic and Cretaceous, appears to have exceeded all the world besides, in the number and size of its Reptiles. Mesozoic time is well named the *Age of Reptiles*.

The Birds of the age, or at least some of them, partook of the reptilian features of the time; some of them having long tails like the associated Reptiles (though feathered tails), and free metacarpals; and several different groups of Birds having reptile-like teeth. The Reptilian Birds and Pterodactyls were the flying creatures of the age; the Ichthyosaurs and Plesiosaurs and the like, the "great whales"; the Crocodiles and Dinosaurs, the dominant life of the estuaries and of the land. Even the Mammals bore a reptilian character, being mostly, and probably exclusively, Monotremes and Marsupials. The Monotremes resemble Reptiles in being oviparous, and in numerous anatomical characters. And the Marsupials, though viviparous, have not attained to the typical mammalian character of placental nutrition of the embryo (page 86).

3. *Introduction of Cenozoic Features.* — Among plants the first of Angiosperms are found in the Cretaceous. These become the characteristic plants of Cenozoic time. Among Vertebrates there was a great expansion of the group of Teleosts, or Osseous Fishes, the species characteristic of earlier time having been either Selachians, Placoderms, Ganoids, or Dipnoans (page 283). The earliest species of the modern genus *Crocodilus* occur in the Cretaceous; the first of Birds in the Jurassic — Reptilian Birds; the first of Mammals in the Triassic — probably Monotremes.

Of the classes of Vertebrates, Fishes commenced in the early Paleozoic, Amphibia and Reptiles in the later Paleozoic, Mammals in the early Mesozoic, and Birds in the middle Mesozoic.

DISTURBANCES CLOSING MESOZOIC TIME.

The Post-Mesozoic, or Laramide, Revolution. — The close of Mesozoic time was marked by the making of the greatest of American mountain systems. The Laramide mountain system extends along the whole line of the summit region of the Rocky Mountains from near the Arctic Ocean to central Mexico — a distance exceeding 4000 miles. In the middle latitudes of the United States, it includes the Wasatch Range of Utah and other ranges to the east as far as the Front Range of Colorado.

In the Laramide system, as in the earlier Taconic and Appalachian systems, there had been an accumulation of many thousands of feet of strata in a geosyncline, which was in progress through Paleozoic and Mesozoic time; and the final orogenic catastrophe was of the same general nature.

It is also probable that in South America, at this same time, another system of ranges of as great a length was made along the Andes, and that consequently the mountain-making movements of America at the close of the Cretaceous extended through nearly one third of the earth's circumference.

The mountain-making of this time was accompanied by extensive igneous outflows. Trachyte eruptions took place in the Wasatch Mountains.

The eruption of the trap of the Deccan in India (page 189), the most colossal outflow of igneous rock of which we have evidence, took place at or near the close of the Cretaceous.

Change of Fauna and Flora.—The disappearance of life at this crisis was so extensive that no species of the Cretaceous era, except some Foraminifers and land plants, have yet been identified with certainty in any rock of the following era. This is another great feature in which the Post-Mesozoic revolution was like the Post-Paleozoic. Not only species, but also many of the families and orders characteristic of the Mesozoic disappeared. Here ended the reign of Reptiles, all the characteristic Mesozoic kinds —the Dinosaurs, Enaliosaurs, Pterosaurs, and others—becoming extinct. The Ammonites also, and the Belemnites, with many of the genera of other classes of Mollusks, disappeared. Among plants, the Cycads, which were a prominent feature of the early Cretaceous forests, even in Arctic lands, later retreated southward, and became confined to the warm-temperate and tropical zones, where the few species now existing are to be found.

As in other such exterminations, the extinction of life was not universal. The survival of the genera and families proves that there was no cataclysmic break in the succession of life; and some regions may have suffered little extermination. All that can be affirmed is, that the fossils of the Tertiary era, the next after the Cretaceous, include, so far as yet discovered, no marine Cretaceous species, except a few species of Foraminifers, and no Cretaceous species of terrestrial Vertebrates.

As to the causes of so remarkable a change in the life of the globe, the remarks made on page 330 in reference to the Appalachian revolution are applicable here. Probably the extinction of species at the close of the Mesozoic was in great degree due to climatic changes. The emergence from the ocean of one third of North America, and probably of as large a part of South America, and of large portions of other continents, with the resultant changes in the paths of ocean currents, and the formation of lofty mountain ranges, must have produced very appreciable changes of climate. This may account for much extinction of species even in regions where the Cretaceous strata and the overlying Tertiary are perfectly conformable.

IV. CENOZOIC TIME.

CENOZOIC TIME includes two eras: — 1, THE TERTIARY ERA, or AGE OF MAMMALS; and 2, THE QUATERNARY, or AGE OF MAN.

General Characteristics. — In the transition to this æon the life of the world takes on a new aspect. Trees of modern types — Oaks, Maples, Beeches, etc., and Palms — unite with Conifers to make the forests; Mammals of great variety and size — Ungulates, Carnivores, and others, successors to the small oviparous and semi-oviparous Mammals of the Mesozoic — tenant the land, in place of Reptiles; typical Birds and Bats possess the air, in place of Reptilian Birds and Pterodactyls; Whales, and Teleosts, with Sharks mainly of modern type, occupy the waters, in place of Enaliosaurs, and almost to the exclusion of the ancient tribes of Cestraciont Sharks and Ganoids. Finally Man appears, when Mammals are passing their maximum in grade and magnitude, and becomes the dominant species of the finished world.

tains, between the Wasatch and the Front Ranges of Colorado; another, still larger (W, on the map), lies north of the Uinta Mountains. In the later Tertiary, the lakes of the summit region were drained, and great lakes were formed west, and especially east, of that region. The situation of these lakes indicates that the Rocky Mountain region in general was much less elevated at the beginning of the Tertiary than at present.

ROCKS: KINDS AND DISTRIBUTION.

The marine and lacustrine formations are independent in their fossils, and are nowhere interstratified. Moreover, as geographical diversity of faunas has increased through all geological time, the fossils of the Atlantic and Pacific Borders are almost wholly of different species. It is therefore impossible to make any exact correlation of the formations of the different regions.

The most northerly outcrop of the Eocene on the Atlantic Border is in New Jersey. The formation appears in that state as a narrow and interrupted belt. It is wider in Maryland and Virginia, and still wider in South Carolina. But it is best displayed on the Gulf Border.

The Miocene appears on Marthas Vineyard, and dredgings on Georges Bank and the Grand Bank of Newfoundland indicate that the deposit continues under the shallow sea east of New England. It extends continuously from New Jersey to North Carolina, is represented by isolated patches in South Carolina, is well developed in Florida, and extends along the Gulf Border to Texas and beyond, though partly covered by later deposits.

Patches of marine Pliocene appear at various points along the Atlantic Border, but the formation attains its most extensive development in Florida (Floridian formation). Along the Gulf Border lacustrine deposits of late Tertiary age occur in various places.

The Tertiary rocks are generally but little consolidated; they consist mostly of compacted sand, pebbles, clay, earth, that was once the mud of the sea bottom or of estuaries or lakes, mixed often with shells. They are, indeed, such deposits as are now forming along seashores, and in shallow bays, estuaries, and lakes, or in shallow waters off a coast. There are also limestones made of shells, and others of corals, resembling the reef rock of coral seas. The latter are found mainly in the states bordering on the Mexican Gulf. Another variety of rock is buhrstone, a siliceous rock, cellular by reason of the removal of fossil shells by solution, used, on account of its being so hard and at the same time full of irregular cavities, for making millstones. It occurs in the Eocene of South Carolina, Georgia, and Alabama. Beds of greensand and of lignite or coal occur in some of the deposits. Beds of Diatoms and Radiolarians are sometimes of considerable thickness. In general, the Tertiary rocks differ from those of earlier periods in that the character of the beds of the same horizon is apt to vary from mile to mile, instead of persisting over large areas. There are, however, some exceptional cases of Tertiary beds whose character is nearly uniform over considerable areas. The lacustrine beds of the Interior are remarkable for the treasures of fossil Mammals which they have yielded. Local lignitic beds of lacustrine origin are scattered over various parts of the country. One at Brandon, Vermont, supposed to be of Eocene age, is famous for the fossils it has yielded.

The Tertiary of Great Britain (11, on map, page 295) occurs mostly in the southeastern part of England, in the London basin, and on the southern and eastern borders of the island, adjoining the Cretaceous. The large areas are mostly Eocene (including Oligocene); a narrow strip along the coast of Norfolk and Suffolk is Pliocene.

On the continent of Europe, the Paris basin is noted for its Eocene strata and their fossil Mammals. Other Tertiary areas are those of the Pyrenean and Mediterranean regions, those of Switzerland, of Austria, etc. Some of the marine Eocene beds contain Rhizopods (p. 62) ginia, is 30 feet thick, and is many miles in extent; another, near Monterey, California, is 50 feet thick, and the material is as white and fine as chalk, which it resembles in appearance; another, near Bilin in Bohemia, is 14 feet thick.

FIG. 440.

DIATOMS (and other organisms) from Richmond diatomaceous bed: *a*, Pinnularia peregrina; *b*, *c*, Odontidium pinnulatum; *d*, Grammatophora marina; *e*, Spongiolithis appendiculata; *f*, Melosira sulcata; *g*, same, transverse section; *h*, Actinocyclus Ehrenbergii; *i*, Coscinodiscus apiculatus; *j*, Triceratium obtusum; *k*, Actinoptychus undulatus; *l*, Dictyocha crux; *m*, Dictyocha; *n*, fragment of Actinoptychus senarius; *o*, Navicula; *p*, fragment of Coscinodiscus gigas.

The material from the latter place was used as a polishing powder (and called Tripoli, or polishing slate) long before it was known that its fine grit was owing to the remains of microscopic life. Ehrenberg has calculated that a cubic inch of the fine earthy rock contains about forty-one thousand millions of organisms. Such accumulations of Diatoms are made both in fresh waters and salt, and in those of the ocean at all depths. A group of Diatoms from the Richmond bed is shown in Fig. 440.

Animals.

The most prominent fact with regard to the Tertiary Invertebrates is their general resemblance to modern species. Although a number of the genera are extinct, and nearly every Eocene species, there is still a modern look in the remains, and the specimens have often the freshness of shells from a modern beach. Only a special student of the Mollusca can distinguish the Tertiary species from those now living. After the Eocene, species of the present time begin to be abundant. The common Oyster and Clam have been found fossil in deposits believed to be of Miocene age.

Remains of Insects are more abundant and varied than in any previous era. All the important orders are represented, including the Lepidopters (Moths and Butterflies), which probably do not occur in any earlier formation. More than 2000 species of Insects, in wonderfully perfect state of preservation, have been obtained from the Amber of the Baltic shores. The Amber is a fossil resin, derived from Coniferous trees of the Upper Eocene (Oligocene) period; and the Insects were caught in the resin while it was still liquid, and thus effectually embalmed. Florissant, Colorado, is a famous locality for Eocene Insects; and Oeningen in Switzerland, and Radoboj in Croatia, are among the richest Miocene localities.

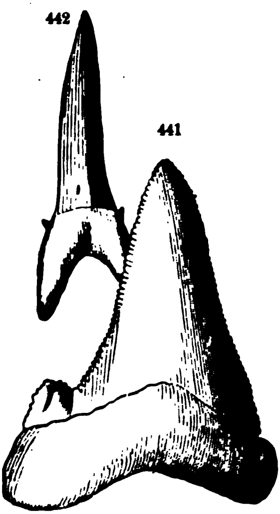
With regard to Vertebrates, the points of special interest are the following: —

1. In the class of Fishes: (1) Teleosts, or Fishes allied to the Perch and Salmon, are, as already stated, the prevalent group; (2) sharp-toothed Sharks are abundant, some of them having teeth 6 inches long and nearly 5 inches broad. The teeth of Sharks are the most durable part of

the skeleton; they are very abundant in both Eocene and Miocene beds. Fig. 441 represents a tooth of *Carcharodon angustidens*. The larger teeth above alluded to belong to *Carcharodon megalodon*, and are found at different places on the Atlantic Border from Marthas Vineyard southward. Fig. 442 represents the tooth of another common kind of Shark, a species of *Lamna*, from the Eocene.

2. In the class of Amphibians: Only the modern groups of Salamanders and Toads and Frogs are represented.

Figs. 441, 442.



SELACHIANS: FIG. 441, tooth of Carcharodon angustidens; 442, Lamna elegans.

3. In the class of Reptiles: Crocodiles and Turtles are numerous. The shell of one of the Pliocene turtles, found fossil in India, had a length of 12 feet, and the animal is supposed to have been 20 feet long.

4. In the class of Birds: The species found are not long-tailed, or in any respect reptilian, but resemble modern Birds; they are related to the Geese, Pelicans, Petrels, Herons, Rails, Pheasants, Eagles, Owls, Doves, Parrots, Woodpeckers, Sparrows, and other kinds.

5. In the class of Mammals: The typical (Placental) Mammals attain a remarkable development. In the Mesozoic, probably all the Mammalian remains are those of Marsupials and Monotremes. But the very earliest Eocene deposits contain remains of a number of orders of Placental Mammals. Before the close of the Eocene, most of the principal orders now in existence had already appeared, in addition to some orders now extinct. There were already, in the Eocene, Insectivores, Bats, Carnivores, Lemurs, Rodents, Ungulates, and Whales. Before

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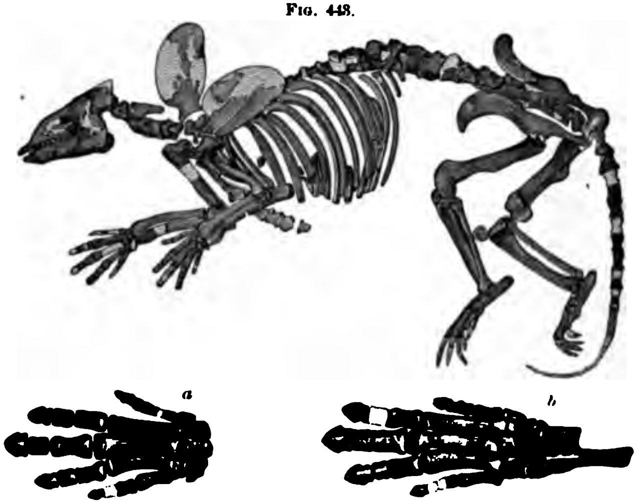
the close of the Miocene, Edentates and Monkeys were added to the list.

Many of the Eocene Mammals exhibit remarkably generalized, or primitive, characters. They have the typical number of teeth (44), and have the molars of simple form with crowns showing three tubercles. Their feet are five-toed, and plantigrade (*i.e.*, the entire foot, even to the wrist or heel, rests upon the ground); and the bones

FIG. 448.



UNGULATE: Phenacodus primævus, $\times \frac{1}{15}$; *a*, fore foot; *b*, hind foot.

of the wrist and ankle are in parallel series. The two bones of the forearm (radius and ulna), and the corresponding bones of the leg, are distinct from each other. In later times, some of the Ungulates have departed most widely from these primitive characters, as may be seen in the Horse, with its smaller number of teeth, complicated enamel folds in its molars, fingers and toes reduced to one, only the finger nails and toe nails (hoofs) reaching the ground, bones of wrist and ankle interlocking, bones of the forearm united (the ulna becoming little more than a rudiment), and the leg showing a like modification. The number of teeth has suffered reduction in almost all the later Mammals ; but others of the primitive characteristics which have been mentioned are retained in many groups of modern Mammals (some of them in Man himself).

In the earliest Eocene, some of the representatives of the Ungulate series exhibited all the primitive characters just enumerated. Such a primitive Ungulate as is shown in Fig. 443 differs but little from the types of Carnivores (Creodonts) that existed in the same early Eocene strata. The various orders had not then become as strongly differentiated as they were destined to become in later times. Before the close of the Eocene, Ungulates and Carnivores had diverged much further from each other, and presented themselves in much more characteristic forms. There is perhaps no finer illustration of the theory of evolution than that which is presented in the progress of the Ungulates from the extremely generalized forms of the earliest Eocene to such specialized forms as the Horses and Ruminants of to-day.

Another noteworthy general fact in regard to the Mammals of the early Tertiary is the small size of their brains, as compared with later species, as illustrated in Figs. 444–446.

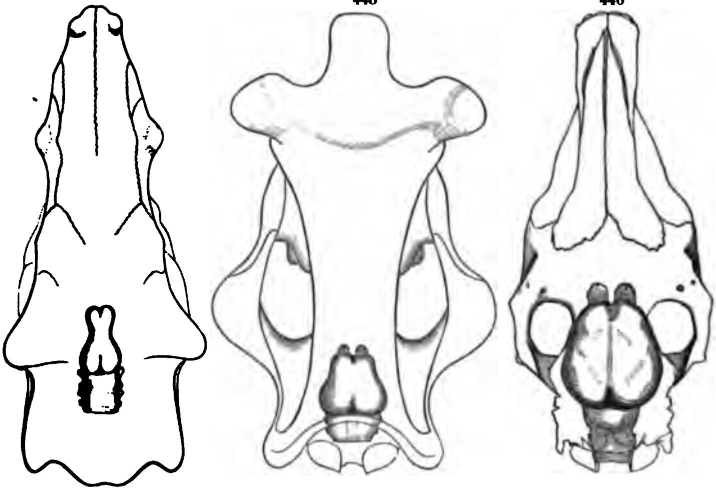
Cuvier first made known to science the existence of Tertiary Mammals of extinct species. The remains from the earthy beds about Paris had been long known, and were thought to be those of modern beasts. But, by careful study and comparison with living animals, Cuvier was enabled to bring the scattered bones together into skeletons, ascertain the orders to which they belonged, and determine the food and mode of life of the extinct species. Cuvier acquired his skill in the interpretation of fossils by observing the mutual dependence which subsists between all parts of a skeleton, and, in fact, all parts of an animal. A sharp claw is evidence that the animal has trenchant or cutting molar teeth, and is a flesh-eater ; a hoof, that

[redacted]

he has broad molars, and is a grazing species; and, further, almost every bone has some modification showing the group of species to which it belongs, and may thus be an indication, in the hands of one well versed in the subject, of the special type of the animal, and of its structure, even to its stomach within and its hide without. In thus applying comparative anatomy to the interpretation of fossils, Cuvier laid the foundation of a new department of science — paleontology.

FIGS. 444–446.

444 445 446



Illustrations of relative sizes of brains: Fig. 444, Dinoceras (Eocene); 445, Titanotherium (Miocene); 446, Equus (Recent).

One genus of these Paris beasts from the middle Eocene beds is named *Palæotherium*, from the Greek *παλαιός*, ancient, and *θηρίον*, wild beast. It is related to the modern Tapirs, though it had a longer neck and a more slender and graceful form. It was in some respects intermediate between the Tapir and the Horse. The largest species of the genus was of the size of a Horse. *Palæotherium* was a representative of the Perissodactyls — Ungulates having an odd number of toes (at least in the hind feet).

[illegible] representatives of [illegible] and the [illegible] development [illegible] [illegible] differences [illegible]. The fauna of [illegible] carnivores [illegible]

Tertiary [illegible]

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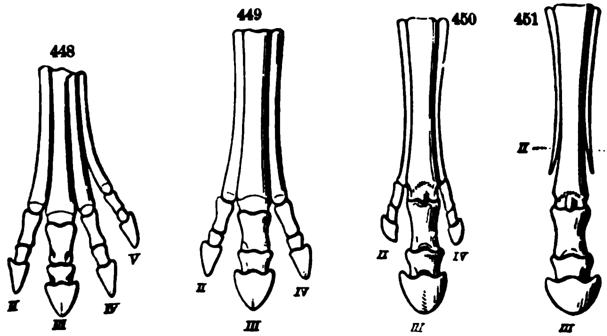
The lacustrine deposits of the Rocky Mountain region have yielded a wonderfully rich harvest of Mammalian remains. The remarkably primitive Ungulate, *Phenacodus*, shown in Fig. 443, is from the lower Eocene (Wasatch) beds of Wyoming. From the Middle Eocene (Bridger group) of the Green River basin, north of the Uinta Mountains, a large number of species have been obtained. The skull of one kind, of elephantine size, having six horn cores, and called by Marsh *Dinoceras*, in allusion to

FIGS. 448-451.



EQUIDÆ: Fig. 448, fore foot of Orohippus (Eocene); 449, Anchitherium (Miocene); 450, Hipparion (Pliocene); 451, Equus (Recent).

its horns, is represented in Fig. 447. There was also one of the earliest genera of the Horse tribe, called *Orohippus;* and it is remarkable that these Eocene Horses had four usable toes in the fore feet (Fig. 448), and three in the hind feet, instead of the single toe of the modern Horse. The relation of the foot of the latter to different kinds of Tertiary Horses is illustrated in Figs. 448–451.

In Fig. 451 it is shown that the modern Horse has one usable toe, the third, and rudiments of two others, the second and fourth, in what are called the splint bones. In *Hipparion*, of the Pliocene (Fig. 450), the second and fourth have hoofs, but they are so short as not ordinarily to reach the ground. In *Anchitherium*, of the Miocene (Fig. 449), the second and fourth toes come to the ground, and are therefore usable. In *Orohippus* (Fig. 448), which was not larger than a Fox, there are four toes, and all are usable.

Other Wyoming species are related to the Tapir and Hog, some approaching in characters the Paris *Palæotherium*. There were also Lemurs, Creodonts (animals related to Carnivores in form and habit, but retaining some of the primitive characteristics of Insectivores), Bats, Moles, and other Insectivores, Rodents, and Marsupials.

The Lower Miocene beds of the "Bad Lands," on the White River (regarded by W. B. Scott as Oligocene),

Fig. 452.

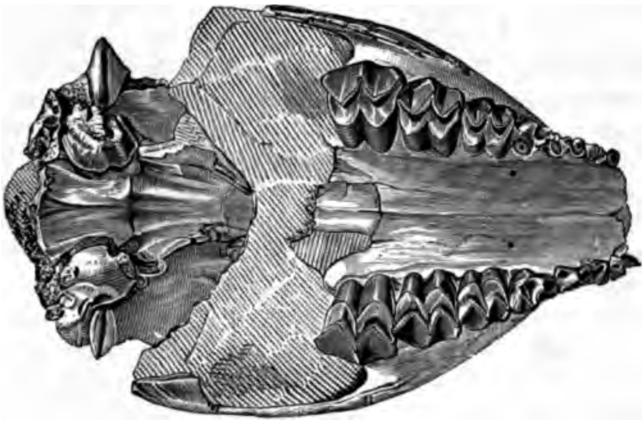
Ungulate: tooth of Titanotherium Prouti, × ½.

have afforded remains of other Mammals. Among them are several Carnivores related somewhat to the Hyena, Dog, and Panther; many Ungulates, including several species of Rhinoceros, and forms approaching the Tapir, Peccary, Deer, Camel, Horse; also several genera of Rodents. Fig. 452 represents a tooth of *Titanotherium*, an animal related to the Tapir and *Palæotherium*, but of elephantine size, standing probably 7 or 8 feet high. The skull in this genus shows a pair of large horn cores on the boundary between the frontal and the nasal bones — a structure not found in any Perissodactyl now living. Horns in pairs are at present confined to the Artiodactyls.

Fig. 453 represents the skull of another Miocene Mammal, called *Oreodon*, which is intermediate between the

Deer, Camel, and Hog. Remains of a Camel and Rhinoceros, and of some tapir-like beasts, have been found in the Miocene of the Atlantic Border.

FIG. 453.



UNGULATE: Oreodon gracilis.

In the Upper Miocene beds (Loup Fork group) of Nebraska and other localities (considered Pliocene by some geologists), still other species occur, including Camels, a Rhinoceros, a Mastodon, Horses, Deer, a Wolf, a Tiger, Weasels — a range of species quite Oriental in character.

FIG. 454.

PROBOSCIDEAN: Dinotherium giganteum, $\times \frac{1}{30}$.

Among Mammals of the European Miocene there were Horses, Rhinoceroses, Deer, and other Ungulates, including two genera (*Dinotherium* and *Mastodon*) of the remarkable suborder of Proboscideans. In the genus *Dinotherium*, the tusks were in the lower jaw, as shown in Fig. 454. The Elephant, now the only surviving genus of Proboscideans, did not appear until the Pliocene. The earliest Oxen occur in the Pliocene of Europe and India.

There were also in the European Miocene and Pliocene many Carnivores, besides Monkeys, Aard-varks, etc.

GENERAL OBSERVATIONS.

Geography: Mountain-making. — The Tertiary era was characterized, both in the Old World and the New, (1) by the approximate completion of the work of rock-making on the borders of the continents, so that the land areas gained nearly the outlines which they have at present; (2) by great orogenic movements, in which most of the loftiest mountain ranges of the globe acquired at least a considerable part of their present elevation.

In North America, by the close of the Tertiary, the continent had reached substantially its present extent, along the Atlantic, Gulf, and Pacific Borders, and the great lakes of the Rocky Mountain region had been drained.

At the close of the Miocene, the Coast Range of Oregon and California experienced a second uplift (see page 362), Cretaceous, Eocene, and Miocene strata being tilted and more or less folded.

But the most remarkable geographical change in North America was a great geanticlinal movement affecting the whole Rocky Mountain region. The long persistence of lakes in the Rocky Mountain region indicates that the elevation was not great in the Eocene and Miocene, and that a large part of the movement took place in Pliocene time. The Cretaceous beds (which must have been originally at or near sea level) have an altitude (in spite of great denudation) of 13,000 feet in parts of the United States, 10,000 feet in central Mexico, and 4000 feet in British America near the Arctic Ocean. This elevation is partly due to the post-Mesozoic orogenic movement (Laramide revolution) described on page 383, and partly to the Tertiary geanticlinal movement. But nearly horizontal Tertiary strata are found in Wyoming, north of the Uinta

Mountains, at an elevation of more than 9000 feet, and in the High Plateaus of Utah at an elevation of more than 10,000 feet.

The Sierra Nevada (as explained on page 362) was formed by the crushing of a geosyncline at the close of the Jurassic. But much of the height then gained was doubtless lost by erosion. Le Conte has shown by a study of the river valleys that a large part of the present altitude of that range is due to its participation in the great Rocky Mountain geanticlinal movement. The old river valleys of the region have been filled up and obliterated by basaltic eruptions whose date was not far from the close of the Tertiary. The fact that the new valleys have been carved to a far greater depth than the old ones indicates that the region has been greatly elevated.

The formation of the great geanticline was accompanied by the development of numerous faults, some of them having a throw of thousands of feet, having in general a trend approximately parallel with the axis of the mountain chain, and distributed over the whole breadth of the Great Basin, from the Sierra Nevada to the Wasatch, and southward over the High Plateaus of Utah. The steep eastern front of the Sierra is determined by one of these great faults.

In the Orient, the Eocene era was one of very extensive submergence of the land, as shown by the distribution of the Nummulitic beds over Europe, Asia, and northern Africa, as stated on page 390. Before the close of the Eocene, the greater part of these continental seas became dry land, and in general continued so afterwards; for the marine Miocene and Pliocene are, comparatively, of limited extent. Many of the principal mountain ranges of Europe and Asia, as the Pyrenees, Alps, Carpathians, Himalayas, etc., received in Tertiary time a large part of their elevation. The Pyrenees were elevated at the close of the Eocene. The region of the Alps had experienced a number of orogenic disturbances in former times, one of these epochs of disturbance being at the close of the Paleozoic, but the great movement which formed the Alps of to-day dates from the close of the Miocene. The Jura and the Carpathians belong to the same period of disturbance which produced the Alps. The Apennines give evidence of one orogenic movement at the close of the Eocene and another at the close of the Miocene. The Himalayas have Nummulitic (Eocene) beds, at a height of more than 20,000 feet; so that this great chain, although it shows in the region of the Indus evidence of some disturbance before the Eocene, was not completed till after the deposition of the Nummulitic Limestones. Whether the principal movement of elevation was at the close of the Eocene, or at the close of the Miocene, has not been certainly shown. Some elevation occurred even after the deposit of the Pliocene beds of the Siwalik Hills.

Thus, when the Tertiary era closed, the globe had acquired substantially its present features.

The great geanticlinal movements affecting large areas of the continents probably had their counterpart in a subsidence of great parts of the ocean bottom — the Coral Island subsidence (see page 104).

Gondwana-land, connecting India with southern Africa in late Paleozoic time and throughout Mesozoic time, according to Oldham, sank below the sea in the Tertiary.

Igneous Eruptions. — A great period of igneous eruptions in western North America commenced at the close of the Cretaceous (Laramide revolution), culminated in the Miocene, and may be said to have continued with diminishing intensity to the present time, some of the volcanic cones being not yet extinct. The Tertiary eruptions were in large part fissure eruptions (page 189), though great volcanic cones were also formed. The area in the northwestern United States covered by sheets of eruptive rock is only surpassed by that of the somewhat earlier (Cretaceous) outflows in the Deccan.

Climate. — During the Eocene, Palms abounded in Great *Britain* — evidence of a subtropical or warm-temperate climate in that latitude; and the Arctic regions had forests consisting of Beech, Plantain, Willow, Oak, Poplar, Walnut, Magnolia, Redwood, showing a mean temperature of at least 48° F. (Heer). In the Miocene, southern Europe had a subtropical climate, but England had lost its Palms and was cooler.

In North America, in the early Tertiary, a warm-temperate climate must have extended to the northern boundary of the United States, as shown by the fossil plants at Brandon, Vermont, and in other localities.

The Camels, Rhinoceroses, and other animals of the upper Miocene of Nebraska, seem to prove that a warm-temperate climate prevailed there in that period.

It is therefore plain that the earth had not as great a diversity of zones of climate in the early Tertiary as now; and that Europe was not very much colder in the Eocene period than in the Jurassic era.

II. QUATERNARY ERA.

General Characteristics. — The Quaternary age was remarkable (1) for oscillations of level and climatic changes in high latitudes both north and south of the equator; (2) for the culmination of the type of brute Mammals; and (3) for the appearance of Man on the globe.

Periods. — The periods are three: —

1. The GLACIAL, or the period when, over the higher latitudes, large areas of the continents stood at an altitude considerably greater than at present, and experienced a colder climate, with immense development of glaciers.

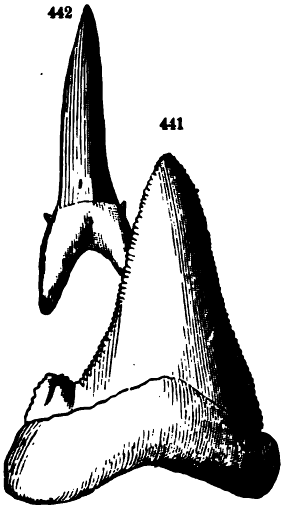
2. The CHAMPLAIN, when the ice disappeared, and the same high-latitude portions of the continent, and to a less extent other regions, were below their present level, and became covered by extensive fluvial and lacustrine formations, and along seacoasts by marine formations.

3. The RECENT period, begun by a rising of the land nearly or quite to its present level.

the skeleton; they are very abundant in both Eocene and Miocene beds. Fig. 441 represents a tooth of *Carcharodon angustidens.* The larger teeth above alluded to belong to *Carcharodon megalodon*, and are found at different places on the Atlantic Border from Marthas Vineyard southward. Fig. 442 represents the tooth of another common kind of Shark, a species of *Lamna*, from the Eocene.

2. In the class of Amphibians: Only the modern groups of Salamanders and Toads and Frogs are represented.

Figs. 441, 442.



Selachians: Fig. 441, tooth of Carcharodon angustidens; 442, Lamna elegans.

3. In the class of Reptiles: Crocodiles and Turtles are numerous. The shell of one of the Pliocene turtles, found fossil in India, had a length of 12 feet, and the animal is supposed to have been 20 feet long.

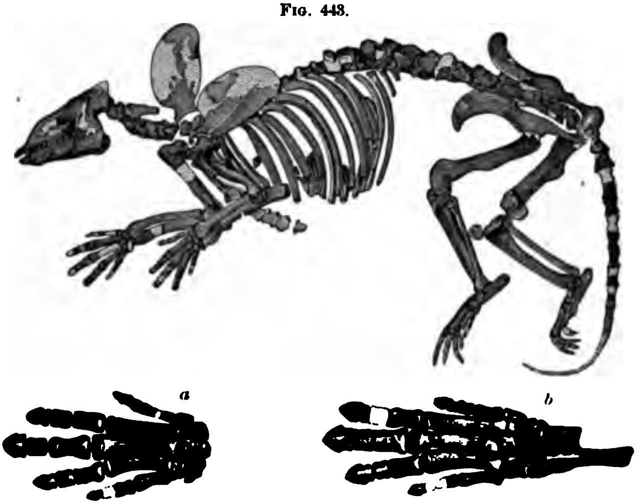
4. In the class of Birds: The species found are not long-tailed, or in any respect reptilian, but resemble modern Birds; they are related to the Geese, Pelicans, Petrels, Herons, Rails, Pheasants, Eagles, Owls, Doves, Parrots, Woodpeckers, Sparrows, and other kinds.

5. In the class of Mammals: The typical (Placental) Mammals attain a remarkable development. In the Mesozoic, probably all the Mammalian remains are those of Marsupials and Monotremes. But the very earliest Eocene deposits contain remains of a number of orders of Placental Mammals. Before the close of the Eocene, most of the principal orders now in existence had already appeared, in addition to some orders now extinct. There were already, in the Eocene, Insectivores, Bats, Carnivores, Lemurs, Rodents, Ungulates, and Whales. Before

the close of the Miocene, Edentates and Monkeys were added to the list.

Many of the Eocene Mammals exhibit remarkably generalized, or primitive, characters. They have the typical number of teeth (44), and have the molars of simple form with crowns showing three tubercles. Their feet are five-toed, and plantigrade (*i.e.*, the entire foot, even to the wrist or heel, rests upon the ground); and the bones

FIG. 443.



UNGULATE: Phenacodus primævus, $\times \frac{1}{15}$; *a*, fore foot; *b*, hind foot.

of the wrist and ankle are in parallel series. The two bones of the forearm (radius and ulna), and the corresponding bones of the leg, are distinct from each other. In later times, some of the Ungulates have departed most widely from these primitive characters, as may be seen in the Horse, with its smaller number of teeth, complicated enamel folds in its molars, fingers and toes reduced to one, only the finger nails and toe nails (hoofs) reaching the ground, bones of wrist and ankle interlocking, bones of the forearm united (the ulna becoming little more than a rudiment), and the leg showing a like modification. The number of teeth has suffered reduction in almost all the later Mammals ; but others of the primitive characteristics which have been mentioned are retained in many groups of modern Mammals (some of them in Man himself).

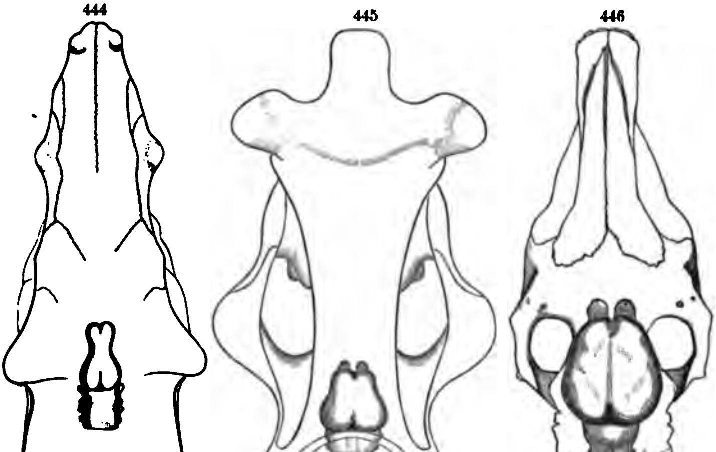
In the earliest Eocene, some of the representatives of the Ungulate series exhibited all the primitive characters just enumerated. Such a primitive Ungulate as is shown in Fig. 443 differs but little from the types of Carnivores (Creodonts) that existed in the same early Eocene strata. The various orders had not then become as strongly differentiated as they were destined to become in later times. Before the close of the Eocene, Ungulates and Carnivores had diverged much further from each other, and presented themselves in much more characteristic forms. There is perhaps no finer illustration of the theory of evolution than that which is presented in the progress of the Ungulates from the extremely generalized forms of the earliest Eocene to such specialized forms as the Horses and Ruminants of to-day.

Another noteworthy general fact in regard to the Mammals of the early Tertiary is the small size of their brains, as compared with later species, as illustrated in Figs. 444–446.

Cuvier first made known to science the existence of Tertiary Mammals of extinct species. The remains from the earthy beds about Paris had been long known, and were thought to be those of modern beasts. But, by careful study and comparison with living animals, Cuvier was enabled to bring the scattered bones together into skeletons, ascertain the orders to which they belonged, and determine the food and mode of life of the extinct species. Cuvier acquired his skill in the interpretation of fossils by observing the mutual dependence which subsists between all parts of a skeleton, and, in fact, all parts of an animal. A sharp claw is evidence that the animal has trenchant or cutting molar teeth, and is a flesh-eater ; a hoof, that he has broad molars, and is a grazing species; and, further, almost every bone has some modification showing the group of species to which it belongs, and may thus be an indication, in the hands of one well versed in the subject, of the special type of the animal, and of its structure, even to its stomach within and its hide without. In thus applying comparative anatomy to the interpretation of fossils, Cuvier laid the foundation of a new department of science — paleontology.

FIGS. 444-446.

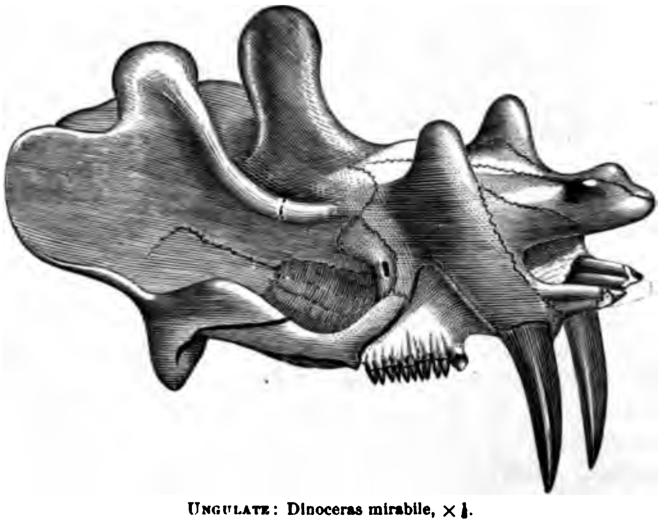
444 445 446



Illustrations of relative sizes of brains: Fig. 444, Dinoceras (Eocene); 445, Titanotherium (Miocene); 446, Equus (Recent).

One genus of these Paris beasts from the middle Eocene beds is named *Palæotherium*, from the Greek παλαιός, ancient, and θηρίον, wild beast. It is related to the modern Tapirs, though it had a longer neck and a more slender and graceful form. It was in some respects intermediate between the Tapir and the Horse. The largest species of the genus was of the size of a Horse. *Palæotherium* was a representative of the Perissodactyls — Ungulates having an odd number of toes (at least in the hind feet), and the middle toe the largest. *Anoplotherium*, *Xiphodon*, and others of the Paris fossils, were representatives of the Artiodactyls, having the number of toes even, and the third and fourth toes about equally developed, as in the Hog, Deer, Ox, etc. It is noteworthy that these two principal suborders of modern Ungulates had become differentiated before the close of the Eocene. The fauna of the Paris Eocene included also some Carnivores, a Bat, and an Opossum.

FIG. 447.



UNGULATE: Dinoceras mirabile, × [illegible].

The marine Eocene deposits of the Gulf States have afforded remains of a species of Whale of great length, called *Zeuglodon*, from ζεύγλη, yoke, and ὀδούς, tooth, in allusion to the fact that some of the teeth have two long fangs which give them a yokelike shape. The bones occur in many places in the Gulf States, and in Alabama the vertebræ were formerly so abundant as to have been built up into stone walls, or burned to rid the fields of them. The living animal was probably 70 feet in length. One of the larger vertebræ measures a foot and a half in length and a foot in diameter.

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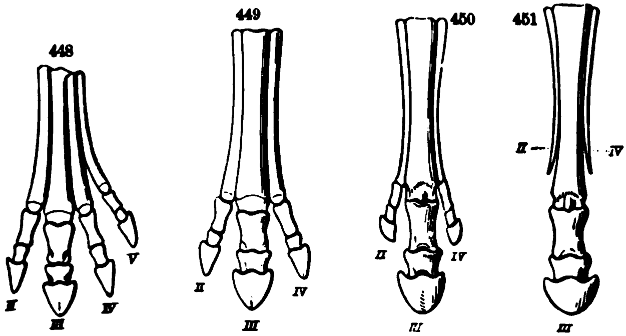

EQUIDÆ: Fig. 448, fore foot of Orohippus (Eocene); 449, Anchitherium (Miocene); 450, Hipparion (Pliocene); 451, Equus (Recent).

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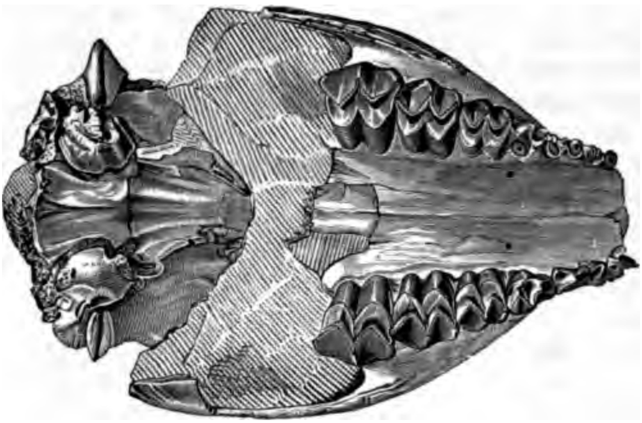

Ungulate: Oreodon gracilis.

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Fig. 454.

Proboscidean: Dinotherium giganteum, $\times \frac{1}{60}$.

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Gondwana-land, connecting India with southern Africa in late Paleozoic time and throughout Mesozoic time, according to Oldham, sank below the sea in the Tertiary.

Igneous Eruptions. — A great period of igneous eruptions in western North America commenced at the close of the Cretaceous (Laramide revolution), culminated in the Miocene, and may be said to have continued with diminishing intensity to the present time, some of the volcanic cones being not yet extinct. The Tertiary eruptions were in large part fissure eruptions (page 189), though great volcanic cones were also formed. The area in the northwestern United States covered by sheets of eruptive rock is only surpassed by that of the somewhat earlier (Cretaceous) outflows in the Deccan.

Climate. — During the Eocene, Palms abounded in Great *Britain* — evidence of a subtropical or warm-temperate climate in that latitude; and the Arctic regions had forests consisting of Beech, Plantain, Willow, Oak, Poplar, Walnut, Magnolia, Redwood, showing a mean temperature of at least 48° F. (Heer). In the Miocene, southern Europe had a subtropical climate, but England had lost its Palms and was cooler.

In North America, in the early Tertiary, a warm-temperate climate must have extended to the northern boundary of the United States, as shown by the fossil plants at Brandon, Vermont, and in other localities.

The Camels, Rhinoceroses, and other animals of the upper Miocene of Nebraska, seem to prove that a warm-temperate climate prevailed there in that period.

It is therefore plain that the earth had not as great a diversity of zones of climate in the early Tertiary as now; and that Europe was not very much colder in the Eocene period than in the Jurassic era.

II. QUATERNARY ERA.

General Characteristics. — The Quaternary age was remarkable (1) for oscillations of level and climatic changes in high latitudes both north and south of the equator; (2) for the culmination of the type of brute Mammals; and (3) for the appearance of Man on the globe.

Periods. — The periods are three: —

1. The GLACIAL, or the period when, over the higher latitudes, large areas of the continents stood at an altitude considerably greater than at present, and experienced a colder climate, with immense development of glaciers.

2. The CHAMPLAIN, when the ice disappeared, and the same high-latitude portions of the continent, and to a less extent other regions, were below their present level, and became covered by extensive fluvial and lacustrine formations, and along seacoasts by marine formations.

3. The RECENT period, begun by a rising of the land nearly or quite to its present level.

The Glacial and the Champlain periods taken together are often called the *Pleistocene*. They are in general not clearly differentiated from each other except in the high-latitude regions which experienced the remarkable changes of level and climate above mentioned.

Physical History of the Quaternary.

1. GLACIAL PERIOD.

The Drift. — The most characteristic phenomenon connected with the Glacial period is a peculiar and widespread deposit over the continents, which gives evidence in general of transportation from the higher latitudes to the lower.

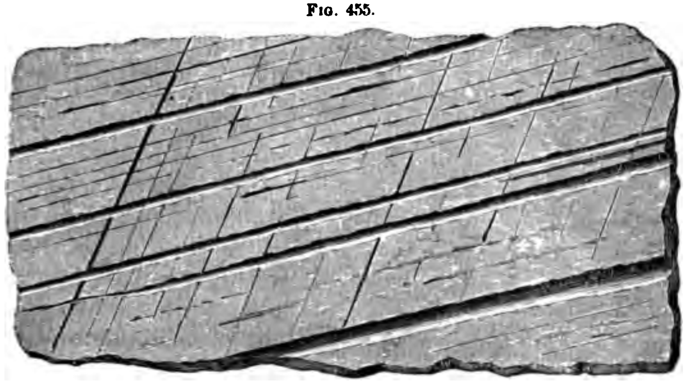
The transported material consists of earth, gravel, stones, and bowlders; and includes, in America, nearly all the earth, as well as stones, of the surface in the latitude of New England and farther north. It extends over hills and valleys, and varies in depth from a few feet to hundreds. A large part of the material is in an unstratified condition, large stones and small, pebbles and sand, being mingled pellmell. Part, especially that in the valleys or depressions of the surface, is stratified, and thus bears evidence of deposition by flowing waters, like fluvial and lacustrine formations. But the greater part of the stratified drift belongs to the Champlain period.

The transported material is called *Drift*, and the unstratified part of it *till* (a word of uncertain origin first applied to this deposit in Scotland). The till, especially its lower part, is often a clayey earth, or a clayey mixture of earth and stones with frequent bowlders, called the *bowlder clay;* it is in general firmly compacted.

The traveled stones are of all dimensions, from that of a small pebble to masses as large as a moderate-sized house. One in Nottingham, New Hampshire, is 62, 40, and 40 feet in its diameters, and is estimated to weigh about 6000 tons. A still larger one in Madison, New

Hampshire, is estimated to weigh 7650 tons. One lying on a naked ledge in Whitingham, Vermont, measures 43 feet in length and 30 in height and width, or 39,000 cubic feet in bulk, and was probably transported across Deerfield valley, the bottom of which is 500 feet below the spot where it lies. Many on Cape Cod are 20 feet in diameter. There are many great bowlders of trap from 50 to 1250 tons in weight along the western border of the Triassic area in Connecticut, the line reaching to Long Island Sound, just west of New Haven; and others of great magnitude occur farther south on Long Island. A bowlder in Ohio,

FIG. 455.



Drift groovings and scratches.

16 feet in thickness, is said to cover three fourths of an acre.

The directions of travel, as learned by tracing the stones in numerous cases to the ledges whence they were derived, are, in general, between southwestward and southeastward. The distance to which the stones were transported in North America is mostly from 10 miles or less to 40 miles, though in some cases as much as 500 miles. The material was carried southward across the depressions now occupied by the Great Lakes and Long Island Sound — the land to the south, in each case, being covered with stones from the land to the north.

Scratches. — The rocky ledges over which the drift was borne are often scratched, in closely crowded parallel lines, as in the preceding figure (Fig. 455), and planed off besides. Besides fine scratches, there are sometimes deep and broad grooves — at times a yard or more deep and several feet wide, as if made by a tool of great size as well as great power. The scratches occur wherever the drift occurs, provided the underlying rocks are sufficiently durable to have preserved them, and they are usually approximately uniform in direction in any given region. In some places two or more directions may be observed on the same surface. They are found in the valleys, and on the slopes of mountains, to a height, on the Green Mountains, of 4400 feet, and, on the White Mountains, of 5500 feet. They have nearly a common course over the higher lands of a region, and cross slopes and sometimes even the smaller valleys, without following the direction of the slope or valley; but, in the great valleys of the land, and sometimes even in the smaller ones, their direction conforms to the trend of the valley. In the Hudson River valley, between the Catskills and the Green Mountains, the scratches have mostly the course of the valley; and also in the valleys of the Connecticut, the Merrimac, and other large rivers.

The stones, or bowlders, of the till are often scratched, as well as the underlying rocks, and in this respect they differ from those of stratified drift; the latter have generally lost all scratches by river abrasion.

Origin of the Drift. — The earliest theory of the Drift attributed its transportation to the tumultuous waves of a deluge sweeping over the land; and the formation was formerly called *Diluvium*, in allusion to this theory. Later it came to be generally admitted that nothing but moving ice could have transported the Drift with its immense bowlders.

When the inadequacy of water alone for the work was recognized, the agency first thought of was that of floating ice in the form of icebergs. Icebergs transport earth and stones, as in the Arctic seas; and great numbers are annually floated south to the Newfoundland Banks, through the action of the Arctic, or Labrador, current, where they melt and drop their great bowlders and burden of gravel and earth to make deposits over the sea bottom. But icebergs could not have covered great surfaces so regularly with scratches. Again, there are no marine relics in the unstratified Drift, to prove that the continent was under the sea in the Glacial period.

These difficulties ultimately led to the well-nigh universal abandonment of the theory of icebergs, and the adoption of the glacier theory first proposed by Louis Agassiz. Glaciers, in the Alps and elsewhere, are now doing precisely such work of transportation as is shown by the Drift; and stones of as great size as are contained in the Drift have in former times been borne by a slowly moving glacier from the vicinity of Mont Blanc, across the lowlands of Switzerland, to the slopes of the Jura Mountains, and left there at a height of over 2000 feet above the level of the Lake of Geneva. Moreover, there are in many places deposits of bowlder clay, made of the earth formed by trituration of stones against stones during the moving of the glacier. Further, there are scratches and grooves, of precisely the same character as those observed in Drift regions, on the granitic and limestone rocks of the ridges; and besides, the transported material is left unstratified over the land, wherever it is not acted upon and distributed by Alpine torrents.

There is a seeming difficulty in the glacier theory, from the supposed want of a sufficient slope in the surface to produce movement. But a slope in the under surface is not needed, any more than for the flowing of pitch. Pitch, deposited in continuous supply on any part of a horizontal plane, would spread in all directions around; and this it would do even if, instead of being horizontal, the surface beneath had an ascending slope. The slope of the upper surface of a plastic or fluid [illegible] mines the direction and rate of flow, not that of the under surface. Hence, if ice were accumulated over a region [illegible] that the upper surface had the requisite slope, there would be motion in the mass in the direction of this slope, whatever the bottom slope might be. At the same time, the slope of the land at bottom, or the courses of the valleys, would determine to some extent the movement at bottom, just as oblique grooves in a sloping board, down which pitch was moving, would determine more or less completely the direction of the movement in the grooves.

The condition of the Drift regions in the Glacial period finds its best illustration, not in the narrow and comparatively shallow glaciers of the Alpine valleys, but in the great ice sheets of Greenland and the Antarctic. Greenland is at the present time a glaciated continent, as the region of Canada and the northeastern part of the United States was in the Glacial period. The ice in Greenland moves where the slope of the surface is less than half a degree.

The phenomena connected with the northern Drift are in general fully explained by reference to a great northern semi-continental glacier as the cause; and those relating to local Drift about high mountains, south of Drift latitudes, by referring them to local glaciers. But floating ice doubtless had some share in the work. Icebergs drifted down the coast, and smaller ones descended rivers, dropping their stones by the way. On the Mississippi, the floating ice may have reached the Gulf of Mexico, and the chilled waters may have destroyed much tropical life.

The occurrence of bowlders near the summit of Mount Washington in the White Mountains proves that the altitude of the upper surface of the ice in that region was 6000 or 6500 feet; and hence that the ice was not less than 5000 feet thick over that part of northern New England. Facts also show that the surface height in southwestern Massachusetts was at least 2800 feet; i southern Connecticut, 1000 feet or more; in the Catskills, 3000 feet (Smock).

Since the slopes of the upper surface of a glacier determine the general direction of movement, and therefore of transportation and abrasion, the lines of scratches or of drift are an indication as to the position of the ice summit. The prevailing direction over the higher lands of New England, New York, and eastern Canada is southeastward, and that over western Ohio and northwestward to the Saskatchewan, is southwestward. (See map on pages 412, 413.) The lines consequently converge northward, toward the part of the Canada watershed northwest from Montreal, and a region extending thence northeastward and northwestward, encompassing the southern part of Hudson Bay; and hence along this course there must have been the summit of a great ice range.

The stones and earth transported by the continental glacier were gathered up mostly by its lower part, from the surface of hills or ridges that projected into it, and even from the plains beneath it. In New England, where there were no peaks rising above the upper surface to be a source of avalanches, as in the Alps, many of the masses thus taken aboard exceed 1000 tons in weight. The mass of decomposed and disintegrated rock which had been accumulating for ages, was extensively scraped up and shoved along. Even the underlying unaltered rock was more or less attacked.

With a thickness of even 2000 feet, the glacier would have had great excavating power. Soft rocks would have been deeply plowed up by it, and all jointed and fissile rocks, soft or hard, would have been torn to fragments, and the loosened masses borne off. By this means, and perhaps most of all by the erosive action of subglacial streams, valleys were deepened and widened.

Area of the Drift in North America. — As already stated, the ice sheet which formed the Drift of Canada and the northeastern United States, had its center over the

[redacted]

Fig. 456.

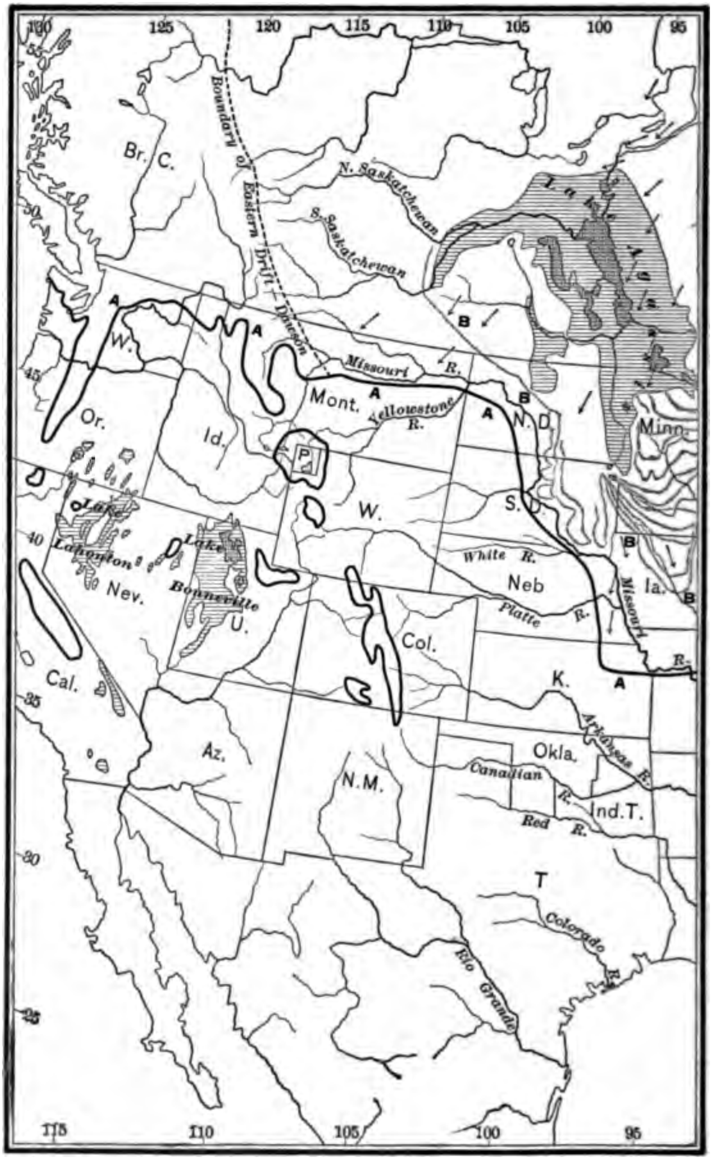


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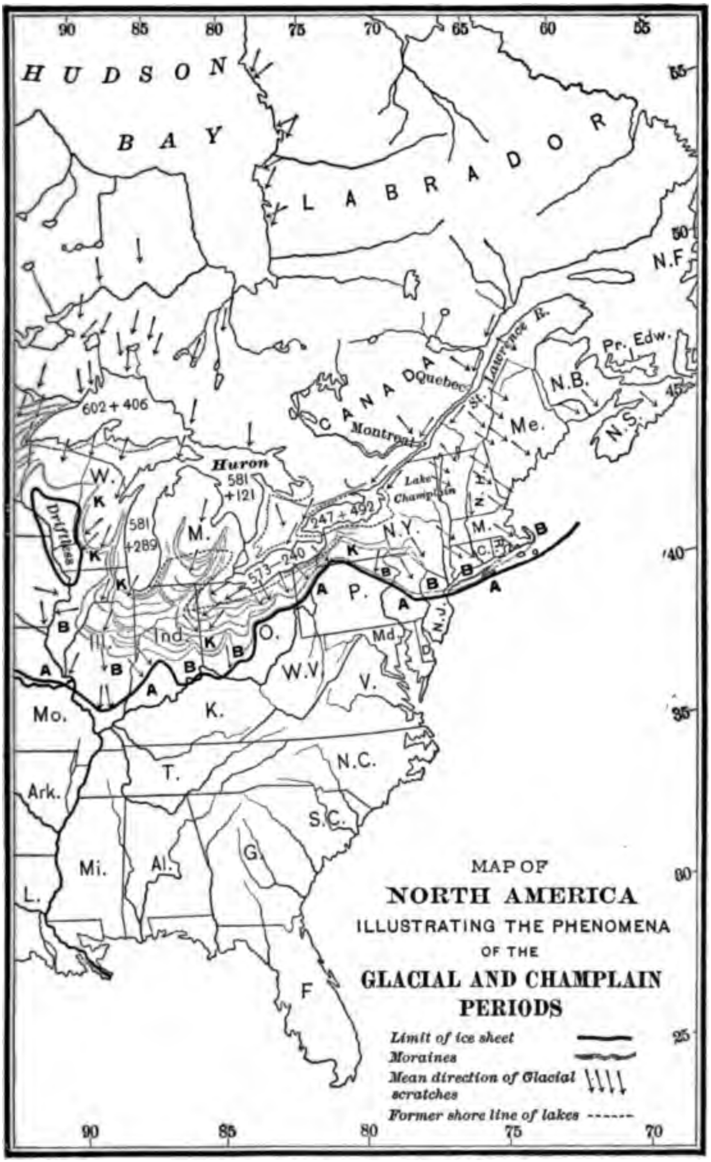
Fig. 456.



highlands which form the watershed between the St. Lawrence basin and Hudson Bay. The extent of the Drift area (and consequently the maximum extension of the ice sheet) is indicated by the heavy line on the map, Fig. 456. South and southeast of New England the line lies outside of the present coast line. It may be traced by the accumulations forming the terminal moraine, through the islands of Nantucket and Marthas Vineyard, and near the south shore of Long Island. It extends westward and northwestward across New Jersey and Pennsylvania, crosses the boundary of New York in a great northern bend, follows a general southwesterly course through western Pennsylvania, Ohio (crossing once into Kentucky), Indiana, and reaches in southern Illinois the lowest latitude which it anywhere attains (below 38°). Thence it extends nearly westward through Missouri into eastern Kansas, where it bends sharply northward. Near the western boundary of North Dakota it passes above the parallel of 47°. Thence the line continues nearly westward across Montana till it reaches the independent area of Drift formed by the ice sheet of the northern Rocky Mountains. The contrasted meteorological conditions of eastern and western North America explain in the main the form of the southern boundary of the Drift. In the east, where the precipitation is great, the boundary lies near the parallel of 40°. In the arid west, the boundary recedes far to the north. Various local conditions, chiefly topographical, serve to explain the minor curves of the boundary, as also the occurrence of two isolated driftless areas within the drift region, one of which (much the larger of the two), lying mostly within the state of Wisconsin, is represented on the map.

Besides the great area of the northeastern (Laurentide) ice sheet, glacial areas were developed in various parts of the Rocky Mountain region. In the extreme northwest of the United States and in British Columbia, a large area of the northern Rockies was covered with a great ice sheet, whose eastern edge met the western edge of the Laurentide ice sheet. The boundary between the two is represented by a dotted line on the map. The ice sheet of the Rocky Mountains in British Columbia had a northern, as well as a southern, limit, since, although the cold increased northward, precipitation decreased. The extreme northwest of British America, and Alaska (with the exception of its high mountain areas), were left uncovered by ice.

Farther south, local areas of glaciation were developed in some of the higher parts of the Rocky Mountain region, as in the Yellowstone Park and the mountain ranges surrounding it, in the Front Range of Colorado, and in the high Sierra of California.

It thus appears that the glaciation of North America was not due, as has been sometimes imagined, to a great polar ice cap investing all the region of high latitude. The centers of glaciation were in the Laurentide highlands (whose altitude was probably considerably greater than now) and in the Rocky Mountains. The general laws of the relation of accumulation of perpetual snow to climate and topography were the same as now. A study of glaciation in the Old World sustains the same general conclusions.

Subdivisions of the Glacial Period. — The study of every glacier region reveals the fact of oscillation in the extent of the glaciers, dependent upon meteorological fluctuations from year to year. There were on a larger scale oscillations in the extent of the great ice sheets of the Glacial period, though the causes of these oscillations are by no means fully understood.

The Glacial period in North America may be conveniently divided into three epochs, — (1) the *Early Glacial epoch*, or that of the advance and maximum extension of the ice; (2) the *Middle Glacial epoch*, or that of the first retreat of the ice; (3) the *Later Glacial epoch*, or that of the final retreat.

The map (Fig. 456) shows a well-defined line of terminal moraine (*BBB*), which can be traced in substantial continuity from Cape Cod to the Saskatchewan River. In the east, from Cape Cod to central Ohio, that moraine lies only a few miles north of the extreme boundary of the Drift. Farther west, the line of the moraine diverges from the southern boundary of the Drift, and in Wisconsin and Minnesota it sweeps around the driftless area, so as to be more than 500 miles north of the Drift boundary. In British America, in the valley of the Saskatchewan, the line of the moraine lies 300 miles east of the boundary between the Laurentide Drift and the Rocky Mountain Drift.

The line of moraine (*BBB*) marks the limit of the ice sheet in Middle Glacial time, and the distance between the moraine and the southern boundary of the Drift measures the extent of the first retreat of the ice. It is, indeed, possible that the ice may have receded beyond the line of the moraine for a greater or less distance, and then readvanced to the line of the moraine. It is held by Chamberlin and others that the ice had receded so far to the north as to lay bare the greater part of the territory it had previously covered, thus characterizing an *Interglacial epoch* between an earlier and a later Glacial epoch. But it is more probable that the various terminal moraines mark halts in the retreat, or oscillations, more or less extensive, in the position of the ice front, than that the glacial conditions were completely interrupted by one or more than one Interglacial epoch.

During the rapid melting of the ice which characterized the first retreat of the glacier, the Mississippi must have been greatly swollen, and must have carried some floating ice. To this epoch may perhaps be referred the coarse, gravelly deposits of the lower Mississippi valley, with flow-and-plunge structure and other indications of torrential conditions, and occasionally containing stones weighing 100 pounds or more, described by Hilgard under the name of *Orange Sand*, and now included in the *Lafayette* formation of McGee and others. By some geologists, however, the Lafayette formation is believed to be of Pliocene age.

After a long halt at the line *BBB*, the glacier continued its retreat. Numerous terminal moraines mark halts in the retreat or temporary readvances. Some of these moraines are indicated on the map.

By the retreat of the glacier, the surface of the country was left covered with Drift, and diversified by kettle holes, drumlins, eskers, and kames.

Kettle holes are bowl-shaped depressions, often 30 to 50 feet in depth, and 100 to 500 feet in diameter, sometimes even considerably exceeding these dimensions. Each kettle hole was the resting place and often the burial place of a block of ice that became detached from the glacier during the melting, and the final melting of the ice block left a hole in the mass of the Drift deposits. Kettle holes are often occupied by ponds.

Drumlins are elliptical domes, consisting wholly or in part of till.

Eskers and *kames* are ridges and hummocks of coarsely stratified Drift, and are attributed to the action of waters flowing in or under the wasting ice.

By the deposit of Drift over the region forsaken by the ice, river valleys were often obstructed, and the streams compelled to seek new channels. Many lakes were formed in valleys obstructed by dams of Drift, or in depressions left in the irregular distribution of Drift over the country. Some small lakes, moreover, were formed in rock basins excavated by the glacier. The glaciated regions in general are regions abounding in lakes.

The Glacial Period in Other Countries. — The main facts in regard to the Glacial period are the same in northern Europe as in North America. The till presents the same characteristics, and the bed rocks show the same polished and striated surfaces.

winters in an epoch of maximum eccentricity of the earth's orbit. The theory has been briefly explained on page 169. It is very doubtful whether the astronomical conditions assumed by Croll would tend to produce a Glacial period. The great heat of perihelion summers would certainly tend to melt the snow. Moreover, the last period of great eccentricity ended about 70,000 years ago, whereas geological evidence indicates that the close of the Glacial period was much more recent. A corollary of Croll's theory would be the occurrence of glacial and interglacial epochs in the northern hemisphere, alternately with corresponding epochs in the southern hemisphere, during a period of great eccentricity. There is no proof of such alternate glaciation of the two hemispheres, though it is not impossible.

2. CHAMPLAIN PERIOD.

This period is so named from the marine deposits around the shores of Lake Champlain.

The Champlain period is characterized by (1) the continuance of the subsidence which had probably begun in the latter part of the Glacial period, the land in northern latitudes becoming depressed considerably below the present level; (2) a diminution in the slope of southward-flowing rivers, so that they ceased for the most part from the work of erosion, and formed extensive stratified deposits; (3) a climate probably warmer than at present — doubtless, at least in part, the result of the subsidence; (4) the complete disappearance of the great ice sheets.

The deposits of the Champlain period are (1) marine, (2) fluviatile, (3) lacustrine. In general, it is only the marine deposits which afford positive evidence and definite measures of the subsidence; since fluviatile and lacustrine deposits may be formed at various altitudes above the sea level, the height of the water being modified by dams of drift or of ice, and by variations in the ratio of precipitation and evaporation, as well as by changes in the level of the land.

1. **Marine Deposits; Sea Beaches.** — Marine deposits occur as sea beaches, now forming terraces above the present shore lines, or as offshore deposits — the *Leda Clays*.

Along the coast of southern New England, there are apparently no marine Champlain deposits more than 15 or 20 feet above the sea level. The fossiliferous deposits of Sankaty Head, Nantucket, reaching an altitude of about 50 feet, and those at a still higher elevation at Gay Head, Marthas Vineyard, are apparently earlier than the true Champlain deposits. They probably belong to some time of oscillation when the ice front had receded to a greater or less distance from the limit to which it subsequently readvanced (page 416). Marine deposits of Champlain age along the coast of Maine occur at altitudes of 150 to 300 feet. In the basin of the Bay of Chaleurs, the altitude is 200 feet. Along the St. Lawrence valley, the height is 375 feet near the mouth of the Saguenay, 520 feet at Montreal, and 600 feet not far from Lake Ontario, so that the St. Lawrence River was then a vast St. Lawrence Gulf, 500 to 600 feet deep. Even Lake Champlain was an arm of this St. Lawrence Gulf; for beaches containing sea shells occur on its borders to a height of 370 feet at its southern, and about 500 feet at its northern, end; and in one locality remains of a Whale have been found. The Champlain bay had then the great depth of from 700 to 800 feet. At Nachvak, in Labrador, a beach supposed to be of Champlain age is reported at an altitude of 1500 feet. In the region south and west of James Bay, beds with marine shells occur at altitudes of 300 to 500 feet.

The maximum subsidence in eastern North America seems to have been in the region between the St. Lawrence and Hudson Bay — the region probably of maximum elevation in the Glacial period.

On the Pacific coast, marine beaches are reported at altitudes exceeding 1000 feet, but it is not known whether they belong to the same date as the Champlain beds of eastern North America or not.

While there is much uncertainty in regard to the number and extent of climatic and geographical oscillations in Europe, it appears certain that extensive subsidence took place subsequently to the period of maximum glaciation. The subsidence carried parts of Great Britain 500 feet below the present level. In Sweden the depression varied from 200 feet in the southern part to more than 600 in the northern part. At the time of deepest submergence, the Baltic is believed to have been connected with the North Sea by the region of lakes extending westward from Stockholm to the Skager Rack, and with the Arctic Ocean by a channel extending over Finland to the White Sea.

2. **Fluvial Deposits.** — The subsidence of the land northward diminished the slope of all southward-flowing rivers, and consequently diminished their powers of erosion. Moreover, the enormous mass of debris which had been transported by the glaciers, and was set free by their melting, overloaded the rivers. The effect of these causes combined, was the deposit of enormous masses of sediment, filling up the river valleys of the glaciated region to a height now indicated by the highest terraces. The rivers meandered over these great alluvial plains (sometimes many miles in width), and in time of floods spread widely over their surface. These alluvial plains were in fact the flood plains of the Champlain rivers.

The structure of the deposits presents great variations. Some parts consist of fine clays, with regular lamination, indicating deposit in quiet waters, as of lakes. Others consist of coarse sands, gravels, or cobble stones, and show the flow-and-plunge structure and other forms of irregular lamination, indicative of strong currents. In places the northward subsidence must have reduced the slope of streams to zero, so that they would spread out in broad lakes. In other places lacustrine conditions must have been produced by dams of drift or ice. Coarse materials *would often* be brought into the larger streams by tributaries whose slope and velocity were greater than those of the larger streams, and would be piled up as deltas near the mouths of those tributaries. Rapid melting of the ice during part of the time may have increased the volume of water, and so increased the velocity of the streams.

3. **Lakes of the Pleistocene.** — Lake basins in various parts of the country are plainly marked by shore lines formed in Pleistocene time. In some cases the basins are still occupied by smaller lakes, and the old beaches appear as terraces far above the present shore lines. In other cases, the lakes have been drained, so that no considerable remnants now exist. Climatic changes, and dams of drift or of ice, as well as movements of subsidence and elevation, may have been concerned in determining the existence and the boundaries of these lakes. The correlation of the history of the lakes with the history of general continental movements indicated by fiords and by sea beaches, is matter of much question.

Ancient beaches have been observed in many places around the Great Lakes of the Canadian frontier. Some of those which have been most thoroughly studied are shown by dotted lines on the map, Fig. 456. The highest shore line around Lake Superior has an altitude of 500 to 600 feet above the present level of the lake, or of 1100 to 1200 feet above the level of the sea. At the south end of Lake Michigan, the highest shore line is only 45 feet above the present level of the lake. This beach is supposed to be contemporaneous with one around parts of Lake Superior about 400 feet above the lake. A very strongly marked shore line has been traced around the greater part of Lake Ontario, and has been named the Iroquois beach. It has a height above the present water level varying from 116 feet near the western end of the lake to 483 feet at Watertown, New York. The great difference between the altitudes of beaches around the various lakes which have been supposed to be contemporaneous, and especially the great difference between the altitudes of different parts of the same continuous beach (as in the case of the Iroquois beach), is evidence of great changes of relative level in different parts of the lake region.

There seems good reason to believe that at one time the four upper lakes were confluent into one lake, more than 100,000 square miles in area, which has been named *Lake Warren* (in honor of General Warren, the discoverer of Lake Agassiz).

The high level of the water in these Pleistocene lakes has been attributed by many geologists to the presence of the remnant of the continental ice sheet in the St. Lawrence valley, damming up the outlet in that direction, and compelling the waters to seek outlets southward at higher levels. Others hold that, at the time of the existence of these lakes, the ice had already receded from the St. Lawrence valley, and that the great extension of the lakes was due to the Champlain subsidence. At the time of maximum Champlain depression, the Iroquois beach must have been very nearly at the sea level; but the absence of marine fossils shows that Lake Ontario did not (like Lake Champlain) have so free communication with the sea as to become salt. It is supposed by many geologists that, at the time of the Iroquois beach, Lake Ontario communicated with the sea by a channel leading from Rome, New York, to the Mohawk valley, and thence by way of the Hudson; but this is not certain.

The region of Lake Winnipeg was occupied at some time in the Pleistocene by a lake even larger than Lake Warren, which has been named *Lake Agassiz* (see map, Fig. 456). General G. K. Warren, who first made known the fact of the former drainage of the Winnipeg region into the Mississippi by way of the Minnesota, attributed the southward drainage to that high elevation of the northern part of the continent, which existed at the beginning of the Quaternary. According to this view, the beginning of the Champlain subsidence depressed the Winnipeg region so greatly as to form Lake Agassiz. The further progress of subsidence depressed the region to the north so far that Lake Agassiz found an outlet through Nelson River into Hudson Bay, and the Red River of the North began to flow northward instead of southward. According to Upham and others, the southward drainage of the Winnipeg region was due to the presence of the ice sheet, damming up the Nelson River outlet. In the case of Lake Agassiz, as in that of Lake Warren and the other lakes of the Canadian frontier, there is evidence of considerable oscillations of level in the very different altitudes of different parts of the same beach.

Lake Bonneville is the name of a Pleistocene lake occupying a large part of Utah, and *Lake Lahontan* the name of one occupying a large part of western Nevada (see map, Fig. 456). The Great Salt Lake is the diminished representative of the former, while the latter is now represented by still smaller remnants. At one time Lake Bonneville rose so high as to find an outlet through the Snake River and the Columbia, and thus became fresh; but Lake Lahontan never had an outlet. The high level of the water in these lakes is attributed to the cold climate of the Glacial period, which must have diminished evaporation. According to Gilbert, King, and Russell, there is evidence of two high-water stages in each of these lakes, with an intervening epoch in which the lakes were nearly or quite desiccated. It is still uncertain what phases in the Pleistocene history of eastern North America are to be correlated with the alternations of high and low water in these lakes of the Great Basin.

3. RECENT PERIOD.

The Champlain period was brought to a close by a moderate elevation of the land over the higher latitudes, bringing the continent up to its present level. This elevation placed the old sea beaches of the Champlain period

[redacted]

at their present level, high above the sea; that is, over 500 feet near Montreal, 150 to 300 feet on the coast of Maine, and so on, the height of the beaches being a measure of the amount of elevation. River valleys, after the rise, had a steeper slope than in the Champlain period, and hence their flow was increased in velocity. They consequently went on cutting down their beds through the Champlain deposits of the valley to a lower level; and at the time of their annual floods they wore

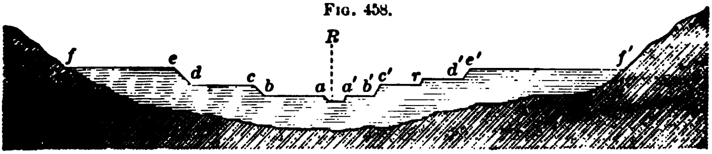
Fig. 457.

Terraces on the Connecticut River, south of Hanover, New Hampshire.

away the deposits on either side of the channel, making thereby an alluvial flat or flood ground; for a river has, in general, a flood ground which it covers in its times of flood, as well as a channel for dry times.

This sinking of the river beds left remnants of the old flood grounds as terraces far above the level of the stream. In the course of the elevation, a series of terraces was often made along the valleys, as illustrated in Fig. 457. A section of a valley thus terraced is represented in Fig. 458. The formation terraced is, as is shown, the Champlain (sometimes in part Glacial Drift); in the Champlain period it filled, in general, the valley across (from *f* to *f'*), excepting a narrow channel for the stream, the whole breadth having been the flood ground of the Champlain river. But, after the elevation began which closed the Champlain period, the river commenced to cut down through the formation, making one or more terraces in it, on either side of the stream. In general, each terrace below the uppermost one indicates a pause in the movement of elevation, being really a remnant of a flood plain formed while the river was nearly at base level (pages 131, 138). In Fig. 458, *R* is the position of the river channel after the terracing; and on either side of it there are terraces at the levels *ff'*, *dr*, *bb'*, and also

FIG. 458.



Section of a valley with terraces.

another on the right side, at *rd'*. These terrace plains are usually the sites of villages. They add greatly to the beauty of the scenery along water courses. The terraces usually fail where the valley is narrow and rocky.

In Europe, the close of the period of subsidence (Champlain) seems to have been marked by a recurrence of Glacial conditions, the northern portions of that continent being again covered with ice, and glaciers extending once more from the Alps over part of lower Switzerland. Proofs of the occurrence of such an epoch are found in the remains of the Reindeer and other sub-arctic animals, in southern France (page 437), in deposits that are subsequent in date to true Champlain deposits.

Modern Changes of Level.

The sea, the rivers, the winds, and all mechanical and chemical forces are still working as they have always worked; and the earth is undergoing changes of level, also, over wide areas, although it has beyond question reached an era of comparative repose.

These changes of level are either paroxysmal — that is, they take place through a sudden movement of the earth's crust, as sometimes happens in connection with an earthquake; or they are secular — that is, they are the effect of a gradual movement prolonged through many years or centuries. The following are some examples: —

1. **Paroxysmal Movements.** — In 1822, the coast of Chile for 1200 miles was shaken by an earthquake, and it has been estimated that the coast near Valparaiso was raised at the time 3 or 4 feet. In 1835, during another earthquake in the same region, there was an elevation, it is stated, of 4 or 5 feet at Talcahuano, which was reduced after a few months to 2 or 3 feet. In 1819, there was an earthquake about the Delta of the Indus, and simultaneously an area of 2000 square miles, in which the fort and village of Sindree were situated, sunk so as to become an inland sea, with the tops of the houses just out of water; and another region parallel with the sunken area, 50 miles long and in some parts 10 miles broad, was raised 10 feet above the delta. These few examples all happened within an interval of sixteen years. They show that the earth is still far from absolute quiet, even in this its finished state.

2. **Secular Movements.** — Along the coasts of Sweden and Finland, on the Baltic, there is evidence that a gradual rising of the land is in slow progress. Marks placed along the rocks many years since show that the change is slight at Stockholm, but increases northward. Evidence of elevation has been obtained from the west coast as well as from the east coast, showing that the apparent elevation is not due to oscillations in the water level of the Baltic. At Uddevalla the rate of elevation is equivalent to 3 or 4 feet in a century.

In Greenland, for 600 miles, from Disco Bay, near

69° N., to the frith of Igaliko, 60° 43′ N., a slow sinking has been going on for at least four centuries. Islands along the coast, and old buildings, have been submerged. The Moravian settlers have had to put down new poles for their boats, and the old ones stand "as silent witnesses of the change."

It is believed also that a sinking is in progress along the coast of New Jersey, Long Island, and Marthas Vineyard, and a rising in different parts of the coast region between Labrador and the Bay of Fundy. There are deeply buried stumps of forest trees along the seashore plains of New Jersey, and other evidences of a change of level (G. H. Cook).

This fact is to be noted, that these secular movements of modern time over the continents are, for the most part, so far as observed, high-latitude oscillations, just as they were in the earlier part of the Quaternary.

Life of the Quaternary.

The history of Quaternary life is remarkable for the extensive migrations occasioned by the great geographical and climatic changes of the era. With the increasing cold of the Glacial period, the range of various species of plants and animals was contracted on the north and extended to the south. With the coming on of the mild climate of the Champlain, there was a corresponding northward shifting of the range of various species. In the northward migration, colonies of northern plants and animals were left in regions of high mountains, far south of their normal range, finding on those summits a congenial climate, and freedom from competition with the southern flora and fauna of the low grounds. Plants and Insects of Labrador and the far north occur on the summits of the White Mountains, the Green Mountains, and the Adirondacks. Analogous facts are reported from the Alps and other mountain regions of Europe. The distribution of the flora and fauna was affected by all the minor oscillations of climate, the more hardy plants and animals crowding upon the edge of the ice sheet, and moving northward with every recession of the front of the ice. While many species only migrated southward and northward with the advance and recession of the ice, other species were exterminated by the climatic changes.

The elevation of land in part of Quaternary time established land connection between the eastern and the western continent by way of the region of Bering Strait, perhaps also by way of the Faroe Islands, Iceland, and Greenland. The British Islands were connected with the continent of Europe, and Europe was connected with Africa across the Mediterranean. More or less of migration took place in all these cases between the areas thus connected.

The Invertebrate animals of the Quaternary, and probably also the plants, were very nearly if not quite all identical with existing species. The shells and other Invertebrate remains found in the beds on the St. Lawrence, Lake Champlain, and the coast of Maine, are similar to those now found on the coast of Maine or Labrador, or farther north.

The life of the Quaternary of greatest interest is the Mammalian, which type, as regards brutes, culminated in the Champlain period. This culmination was manifested in — (1) the number of species, (2) the magnitude of the animals — the Mammalian life of the period exceeding in each of these particulars that of the present time.

Along with the brute Mammals of the Quaternary appeared also Man.

Brute Mammals.

Europe and Asia. — The bones of Mammals are found in caves that were their old haunts; in stratified deposits along rivers and lakes; in sea-border deposits; in marshes, where the animals were mired; in ice, where they have been preserved from decay by the intense cold.

The caves on the continent of Europe were the resort especially of the Cave Bear (*Ursus spelæus*), and those of Great Britain of the Cave Hyena (*Hyæna spelæa*). Into their dens they dragged the carcasses or bones of other animals for food, so that relics of a large number of species are now mingled together in the earth or stalagmite which forms the floor of the cavern. In a cave at Kirkdale, England, portions of a very large number of Hyenas have been made out, besides remains of an Elephant, Lion, Bear, Wolf, Fox, Hare, Weasel, Rhinoceros, Horse, Hippopotamus, Ox, Deer, and other species, all then inhabitants of that country. A cave at Gaylenreuth is said to have afforded fragments of at least 800 individuals of the Cave Bear. The Cave Hyena is regarded as a large variety of the *Hyæna crocuta* of South Africa, and the Cave Lion, a variety of *Felis leo*, the Lion of Africa. But many of the Quaternary species are now extinct.

The fact that the number of species in the Quaternary was greater than now, may be inferred from a comparison of the fauna of Quaternary Great Britain with that of any region of equal area in the present age. The species included gigantic Elephants, two species of Rhinoceros, a Hippopotamus, three species of Oxen, two of them of colossal size, several species of Deer, including the colossal Irish Deer (*Cervus euryceros*), whose height to the summit of its antlers was 10 to 11 feet, and the span of whose antlers was in some cases 12 feet, the Horse, Ass, Wild Boar, Wildcat, Lynx, Leopard, Lion, the huge Saber-toothed Tiger (*Machærodus*), with canines sometimes eight inches long, the Cave Hyena, and Cave Bear, besides various smaller species.

The Mammoth (*Elephas primigenius*) was nearly a third taller than the largest modern species of Elephant. It roamed over Great Britain, middle and northern Europe, northern Asia, even to its Arctic shores, and North America. Great quantities of tusks have been exported from the borders of the Arctic Sea for ivory. These tusks sometimes have a length of 12½ feet. Near the beginning of the century one of these Elephants was found frozen in ice at the mouth of the Lena; and it was so well preserved that wolves and bears ate of the ancient flesh. Its length to the extremity of the tail was 16⅓ feet, and its height 9½ feet. It had a coat of long hair. But no amount of hair would enable an Elephant now to live in those barren, icy regions, where the mean temperature

FIG. 459.

PROBOSCIDEAN: *Mastodon giganteus.*

in winter is 40° F. below zero. Siberia had also a hairy Rhinoceros.

Although there were many Ungulates among the Quaternary species of the Orient, the most characteristic animals were the great Carnivores.

North America. — In the Champlain period, there were great Elephants and Mastodons, Oxen, Horses, Stags, Beavers, and some Edentates, in North America, unsurpassed in magnitude by any in other parts of the world.

Ungulates were the characteristic type. Of Carnivores there were comparatively few species; no true cavern species have been discovered. Fig. 459 (from Owen) represents the specimen of the American Mastodon now in the British Museum. The skeleton set up by Dr. Warren in Boston has a height of 11 feet, and a length, to the base of the tail, of 17 feet. It was found in a marsh near Newburgh, New York. The Mammoth (*Elephas primigenius*) was the most common and wide-ranging species of Elephant in North America, as in Europe and Asia.

FIG. 460.

EDENTATE: Megatherium Cuvieri (× $\frac{1}{75}$).

South America. — South America had, at the same time, its Carnivores and Ungulates; but it was most remarkable for its Edentates, or animals related to the Sloths and Armadillos.

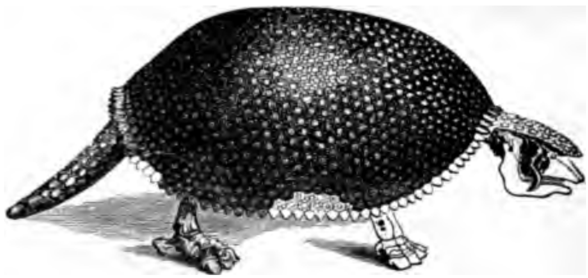
Fig. 460 shows the form and skeleton of one of these animals — the *Megatherium*. It exceeded in size the largest Rhinoceros: a skeleton in the British Museum is 18 feet long. It was a clumsy, slothlike beast, but exceeded immensely the modern Sloths in size. Another group of Edentates, related to the modern Armadillos, had an armor of bony plates developed in the skin, giving them a superficial resemblance to Turtles. One genus named

Glyptodon is represented in Fig. 461, though it has been recently discovered that the tail shown in the figure belongs to another genus. Many of the animals of this group also were gigantic, the *Glyptodon* here figured having had a shell or carapace five or six feet in length.

South America was eminently the continent of Edentates.

Australia.—The Mammals of Australia, in the Champlain period, were almost exclusively Marsupials, as is the case in modern Australia; but these partook of the gigantic size so characteristic of the Mammalian life of the period. The genus *Diprotodon* was as large as a Hippopotamus, and *Nototherium* was as large as an Ox.

Fig. 461.



EDENTATE: Glyptodon clavipes ($\times \frac{1}{35}$).

Conclusions. — The facts sustain the following conclusions: —

1. The Champlain period of the Quaternary was the time of culmination of Mammals, both as to numbers and as to magnitude.

2. The Mammalian faunas of the various continents showed the same ordinal types by which they are now characterized, but many of the species were much larger than now exist. Thus, the Orient had its gigantic Carnivores; South America its gigantic Edentates; Australia its gigantic Marsupials.

3. The climate of Great Britain and the continent

of Europe, where were the haunts of Lions, Tigers, Hippopotamuses, etc., must have been warmer than now, and probably not colder than warm-temperate. The climate of Arctic Siberia was such that shrubs could have grown there to feed the herds of Elephants, and hence could not have been below sub-frigid, for which degree of cold it is possible the animals might have been adapted by their hairy covering.

4. The Champlain period, the meridian time of the Quaternary Mammals, was, accordingly, as before stated, one of warmer climate over the northern continents than the present, and much warmer than that of the Glacial period. The species may have begun to exist before the Glacial period ended; but they belonged preëminently to the Champlain period.

5. The larger part of the great Mammals of the Quaternary disappeared with the close of the Champlain period or in the early part of the Recent period, while others found refuge in the tropics. They were animals of a warmer climate than now belongs to the regions which they then inhabited; and the change to a somewhat colder climate at the close of the Champlain period probably brought about the extermination and forced migration.

Although there is no evidence in North America of a recurrence of Glacial conditions after the Champlain period, it is probable that there may have been oscillations of climate analogous to those of Europe, the climate just at the close of the Champlain period being somewhat colder than at present. Such an oscillation of climate is perhaps indicated by remains of Reindeer which have been found in southern New York, and near New Haven in Connecticut.

Among the Mammals of Europe which existed before the close of the Champlain period, some are now living; as the Reindeer, Marmot, Ibex, Chamois, Elk, Wild Boar, Goat, Stag, Aurochs, Wolf, Brown Bear, and others.

MAN.

Prehistoric Relics of Man in Europe. — The earliest relics of Man in Europe — the region whose prehistoric archæology has been most thoroughly explored — are rude flint implements, as arrowheads, chisels, etc.; flint chippings, or the chips thrown off in making the implements; rude carvings; human bones and skeletons; the bones of the animals used for food, split lengthwise, this being done to get at the marrow; charcoal, and other remains of fires. They occur associated with the remains of the Cave Bear, Cave Hyena, Cave Lion, Mammoth, and other species which have either become extinct or migrated to other regions. They date from the Champlain period, and perhaps, in part, from the Glacial period.

1. *The Paleolithic Epoch.* — As the only implements of early Man in Europe were of stone or bone, the era in human history has been called the *Stone Age*, in distinction from the *Bronze Age* and the *Iron Age*, in which Man had acquired the use of metals. These three stages of civilization (and, for Europe, chronological periods) had been long recognized by students of European archæology. But later studies made it manifest that the Stone Age in Europe not only included a vastly greater lapse of time than the two later ages together, but included widely different types of culture. It became necessary, therefore, to subdivide the Stone Age. The earliest part of that age has been designated the *Paleolithic epoch*, from the Greek *παλαιός*, ancient, and *λίθος*, stone. Geologically, it may be correlated with the Champlain epoch, and perhaps with the latter part of the Glacial epoch. The Paleolithic implements are never polished, and are of ruder make than those of the later part of the Stone Age. Portions of skeletons referred to this era have been found in various countries of Europe. In many cases, however, the evidence of age is more or less dubious. Some

of the skulls and other bones present features which are somewhat simian ; but this is not true of all the supposed Paleolithic remains. The skull found at Engis in Belgium is pronounced by Huxley "a fair average human skull" ; and the same authority declares that "the most pithecoid of human crania yet discovered" (the skull found at Neanderthal in the Rhine valley) can in no sense "be regarded as the remains of a being intermediate between Men and Apes." The antiquity of neither of these famous relics is free from doubt.

2. *The Reindeer Epoch.* — The second section of the European Age of Stone has been called the ***Reindeer***, or ***Mesolithic***, ***epoch***. By many archæologists it is considered only a subdivision of the Paleolithic epoch. It was probably the time of transition from the Champlain to the Recent epoch, which in Europe was marked by a recurrence of Glacial conditions (page 427); and the deposits, which are found in the caves of southern France and elsewhere, are distinguished by the occurrence of large numbers of the bones of the Reindeer, along with the human relics. The flint implements of this epoch are well made, but are still exclusively made by chipping, the men of the Reindeer epoch not having developed the art of grinding and polishing stone; and among the relics there are implements of bone, ivory, and horn, and drawings of animals upon these materials. One of these drawings from southern France, made on ivory, is copied in Fig. 462. It represents the hairy Elephant, or Mammoth; and shows that the men of that epoch were familiar with the Mammoth as a living animal. Remains of the Elephant, Cave Bear, Cave Hyena, Cave Lion, occur in the same deposits, and also others of existing species, as the Elk, Ibex, Aurochs, etc. Perfect skeletons of Man have been found in some of the caverns. Those of southern France are in part of tall stature, — 5 feet 9 inches to 6 feet, — having well-shaped heads, and a large facial angle (85°). One supposed to belong to

this epoch, from a cave at Mentone (on the Mediterranean, near the borders of France and Italy), was of a man fully 6 feet in height; and it lay buried in the stalagmite of the cave, with flint implements and shell ornaments around, and a chaplet of stag's teeth across its head.

3. *The Neolithic Epoch.* — A third epoch is named the *Neolithic* (from νέος, new, and λίθος). The relics include stone implements which are ground and polished, as well as those which are chipped; also broken pottery, and bones of the Dog and (except in the earliest part of the epoch) other domestic animals. The Neolithic men were, therefore, in a much more advanced stage of culture

Fig. 462.

Picture of Elephas primigenius, engraved on ivory, × [illegible].

than those of the preceding epochs. Remains of extinct Champlain Mammals (except the Irish Deer) and of animals which have ceased to exist in central and southern Europe, though surviving in some other region (as the Reindeer), are absent. Neolithic man belongs unquestionably to the Recent period of geological time. The earth and its fauna and flora had acquired substantially their present condition.

The Neolithic race of men in Denmark resembled the Laplanders. Their remains are found in shell heaps (the so-called *kjökkenmödingr*, or kitchen middens) along the shores of the Baltic. These shell heaps are relics of feasts, in which Oysters, Mussels, and other Mollusks apparently formed a considerable part of the food.

To a later time in this epoch belong the earlier lake dwellings of Switzerland — structures built on piles in the lakes, — in which the only implements are of stone and other non-metallic materials. But in the later lake dwellings, about the western Swiss lakes, there are bronze implements, and these are of the Bronze Age. A few of the lake dwellings belong even to the Iron Age. The Neolithic men of the lake dwellings were no longer merely hunters and fishers, but agriculturists, raising wheat and barley.

Prehistoric Relics of Man in Other Countries. — In America, the Indians, at the time of the discovery of the continent by Europeans, were mainly in a Neolithic stage of culture. Rude stone implements have been found in various localities, which have been considered to belong to an earlier Paleolithic race; but the evidence of such an early race is less satisfactory than in Europe, since in some cases the age of the deposit is in dispute, and the localities have not in general been verified by a succession of discoveries. The human skull reported from an ancient gravel in Calaveras County, California, is probably an authentic relic, and is associated with extinct species of Mammals. It is, however, similar to that of a modern Indian, and the implements in the gravels are of Neolithic type. In that locality, some of the Pliocene and Pleistocene Mammalia may have survived to a later date than in most other regions.

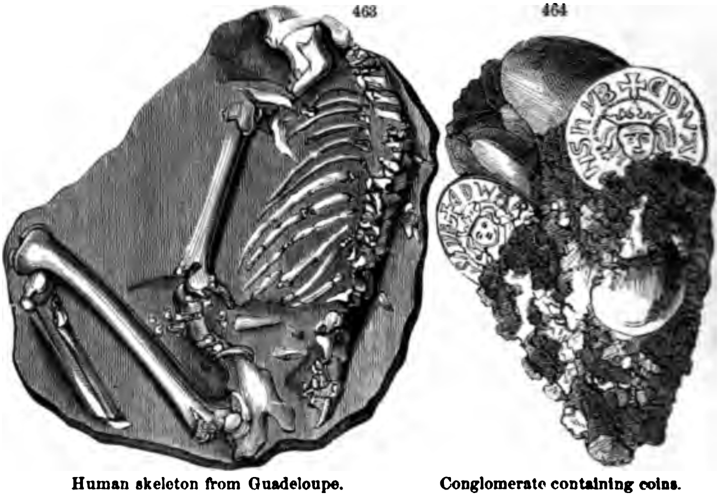
In 1894, Dr. Dubois announced the discovery, in Java, of a portion of a skull, two teeth, and a femur, which he considered to belong to a manlike Ape, and which he named *Pithecanthropus erectus*. The remains appear to be human, but the skull shows simian characters even more strongly marked than those of the Neanderthal skull and others which have been found in Europe. It is uncertain whether the formation in which the relics were found is Pleistocene or Pliocene.

The evidence seems to render it probable that the earliest of prehistoric races, ranging from the East Indies to western Europe, possessed features more simian than are characteristic of any race of men now in existence.

Modern Human Relics. — In modern deposits, buried coins, statues, temples, cities, are found among the earth's fossils, contrasting strangely with the remains of the species

Figs. 463, 464.

463 464



Human skeleton from Guadeloupe. Conglomerate containing coins.

with which the history of the world's life began. Fig. 464 represents a coin conglomerate, containing coins of silver, of the reign of Edward I., found at a depth of ten feet below the bed of the river Dove in England; and Fig. 463, a portion of a human skeleton firmly imbedded in a modern shell limestone of Guadeloupe, the former owner of which was, less than three centuries ago, a fighting Carib.

Man at the Head of the System of Life. — With the creation of Man a new era opens in geological history. In earliest time only matter existed — dead matter. Then appeared life — unconscious life in the plant, conscious and intelligent life in the animal. Ages rolled by, with varied exhibitions of animal and vegetable life. Finally Man appeared, a being made of matter and endowed with life, but, more than this, partaking of a spiritual nature. The systems of life belong essentially to time; but Man, through his spirit, belongs to the infinite future. Thus gifted, man is the only being capable of reaching toward a knowledge of himself, of nature, or of God. He is, therefore, the only being capable of conscious obedience or disobedience to moral law, the only being subject to degradation through excesses of appetite and violation of moral law, the only being with the will and power to make nature's forces his means of progress.

Man shows his exalted nature in his material structure. His fore limbs are not made for locomotion, as in all quadrupeds; they are removed from the locomotive to the cephalic series, being fitted to serve the head, and especially the intellect and soul. Man stands erect, his body placed wholly under the brain, to which it is subservient. His whole outer being, in these and other ways, shows forth the divine nature of the inner being.

Extinction of Species in Modern Times.

Species are becoming extinct in the present epoch, as in the past. Man is now a prominent means of this destruction. The Dodo, a large bird looking like an overgrown chicken in its plumage and wings, was abundant in the island of Mauritius until late in the seventeenth century. In New Zealand have been found remains of almost twenty species of Ostrich-like Birds, known collectively under the native name *Moa*, and referred to the genera *Dinornis*, *Meionornis*, *Palapteryx*, etc. The largest species was 10 or 12 feet in height, and the tibia ("drumstick") 30 to 32 inches long. Some species at least of the Moas may have survived until within a century or two. In Madagascar remains of a still larger bird, but of similar character, occur, called *Æpyornis;* its egg is over a foot

(13½ inches) long. The Great Auk, a bird of northern seas, has become extinct within the present century; the last was seen in 1844. These are a few examples of the modern extinction of species.

The progress of civilization tends to restrict forests and forest life to narrower and narrower limits. The Buffalo once roamed over North America to the Atlantic, but is now practically extinct, except where it is under human protection. The Beaver, Wolf, Bear, and Wild Boar were formerly common in Great Britain, but are now wholly exterminated.

GENERAL OBSERVATIONS ON CENOZOIC TIME.

Contrast between the Tertiary and Quaternary Eras in Geographical Progress. — The study of Cenozoic time has brought out the contrast in the geological work of the Tertiary and Quaternary ages.

The Tertiary in North America carried forward the work of rock-making, and of extending the limits of the dry land southward, southeastward, and southwestward, which had been in progress ever since Archæan time.

The Quaternary transferred the scene of operations to the broad surface of the continent, and especially to its middle and higher latitudes.

Through the Tertiary, the higher mountains of the globe had been rising, and the continents extending; and hence the great rivers with their numerous tributaries — which are the offspring of great mountains on great continents — channeled out the mountains and made valleys and crested heights. In the Glacial epoch this work went forward with special energy. The exposed rocks yielded before the moving glacier, and the fragments torn from the ledges, with the disintegrated material which had accumulated in pre-Glacial time, were carried along to be distributed over the continental surface. Torrents, fed by the melting ice, were also at work, with perhaps even greater abrading power than the ice. Thus the excavation of valleys and the shaping of hills and mountains were everywhere in progress. In the Champlain period, the low level at which the land lay, and the melting of the ice, with the dropping of its earth and stones, enabled the flooded streams to fill the great valleys deep with alluvium. In the Recent period, which followed, the upward movements of the land led to a terracing of the Champlain deposits along the seashores and about the lakes and rivers.

Thus, under the rending, eroding, and transporting power of fresh water, frozen and unfrozen, — eminently the great Quaternary agent, — in connection, probably, with high-latitude oscillations of the earth's crust, the making of the earth was finally completed.

Life.— In Cenozoic time, as in the preceding æons, species were disappearing and others took their places. The Mammals of the early Eocene are different in species from those of the later; and these from the Miocene, the Miocene from the Pliocene, and the Pliocene from the Quaternary.

According to the present state of discovery, Mammals commenced in Mesozoic time, late in the Triassic era, and the Mesozoic species were probably all Monotremes and Marsupials. They were the precursor species, prophetic of that expansion of the new type which was to take place after the Age of Reptiles had closed. In the early Eocene, at the opening of the Age of Mammals, appeared Ungulates and Creodonts of large size. The earliest Ungulates (such as *Phenacodus*, Fig. 443, page 395) were scarcely distinguishable from the earliest representatives of the Carnivores (Creodonts); but more typical representatives of both groups appeared before the close of the Eocene. In the early Tertiary there were Perissodactyls allied to the Tapir and Rhinoceros, and Artiodactyls allied to the Hog. Proboscideans commenced in the Miocene, though the Elephant proper appeared first in the Pliocene. Deer and Antelopes commenced in the Miocene, Oxen in the Pliocene.

GENERAL OBSERVATIONS ON GEOLOGICAL HISTORY.

LENGTH OF GEOLOGICAL TIME.

By employing as data the relative thickness of the formations of the geological ages, estimates have been made of the time ratios of those ages, or their relative lengths (pages 317, 379). These estimated time ratios for the Paleozoic, Mesozoic, and Cenozoic, are 12 : 3 : 1. But the numbers may be much altered when the facts on which they are based are more correctly ascertained. It is quite certain that the Eopaleozoic (Cambrian and Lower Silurian) was, at the least, three times as long as either the Devonian or Carboniferous, and longer than the entire Neopaleozoic; and probable that Mesozoic time was not less than three times as long as Cenozoic.

Hence comes the striking conclusion that the longest age of the world since life began was the earliest — when the earth's population (with the exception of a few Insects and Fishes, in the latter part of the time) included only marine Invertebrates. And the time of the earth's beginnings before the introduction of life must have exceeded in length all subsequent time.

The actual lengths of these ages it is not possible to determine even approximately. All that Geology can claim to do is to prove the general proposition that Time is long. If time from the commencement of the Cambrian included 48 millions of years, which most geologists would pronounce too low an estimate, the Paleozoic part, according to the above ratio, would comprise 36 millions, the Mesozoic 9 millions, and the Cenozoic 3 millions.

One of the means of estimating the length of past time is that afforded by the rate of recession of the Falls of Niagara. The river below the Falls flows northward in a deep gorge, with high rocky walls, for seven miles, toward Lake Ontario. It is reasonably assumed that the gorge has been cut out by the river, for the river is now accomplishing work of this very kind. By certain fossiliferous Quaternary beds over the country bordering the present walls, and by other evidence, it is proved that at least about six miles of the present gorge, and probably the whole seven miles, was made after the retreat of the ice sheet of the Glacial period from that part of the country. A comparison of surveys made respectively in 1842 and 1886 shows that the recession of the apex of the Horseshoe Fall during that time has been at the rate of about four feet per year. On the basis of that determination, the time occupied in the erosion of the entire gorge has been estimated at from 6000 to 10,000 years. It is, however, believed by many geologists that, during a part of the time, the water of the Upper Lakes (Superior, Michigan, Huron) was diverted into another channel. On that supposition, the estimate of the time required for the cutting must be considerably increased—perhaps to about 30,000 years. In any case, when it is considered that the work has been done in a small fraction of the latest and shortest of the geological eras, the calculation may be regarded as establishing, at least, the proposition that Time is long, although it affords no satisfactory numbers.

Besides the estimates of geological time based on processes of erosion and sedimentation, other estimates have been made by physicists based on the conditions of cooling of the earth and the sun.

While neither the geological nor the physical modes of calculation can yield any certain results in the present state of our knowledge, it may be considered probable that geological time from the beginning of the Cambrian is measured by tens of millions, rather than by millions, or by hundreds of millions, of years.

GEOGRAPHICAL PROGRESS IN NORTH AMERICA.

The principal steps of progress in the continent of North America are here recapitulated:—

(13½ inches) long. The Great Auk, a bird of northern seas, has become extinct within the present century; the last was seen in 1844. These are a few examples of the modern extinction of species.

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GENERAL OBSERVATIONS ON CENOZOIC TIME.

Contrast between the Tertiary and Quaternary Eras in Geographical Progress. — The study of Cenozoic time has brought out the contrast in the geological work of the Tertiary and Quaternary ages.

The Tertiary in North America carried forward the work of rock-making, and of extending the limits of the dry land southward, southeastward, and southwestward, which had been in progress ever since Archæan time.

The Quaternary transferred the scene of operations to the broad surface of the continent, and especially to its middle and higher latitudes.

Through the Tertiary, the higher mountains of the globe had been rising, and the continents extending; and hence the great rivers with their numerous tributaries — which are the offspring of great mountains on great continents — channeled out the mountains and made valleys and crested heights. In the Glacial epoch this work went forward with special energy. The exposed rocks yielded before the moving glacier, and the fragments torn from the ledges, with the disintegrated material which had accumulated in pre-Glacial time, were carried along to be distributed over the continental surface. Torrents, fed by the melting ice, were also at work, with perhaps even greater abrading power than the ice. Thus the excavation of valleys and the shaping of hills and mountains were everywhere in progress. In the Champlain period, the low level at which the land lay, and the melting of the ice, with the dropping of its earth and stones, enabled the flooded streams to fill the great valleys deep with alluvium. In the Recent period, which followed, the upward movements of the land led to a terracing of the Champlain deposits along the seashores and about the lakes and rivers.

Thus, under the rending, eroding, and transporting power of fresh water, frozen and unfrozen, — eminently the great Quaternary agent, — in connection, probably, with high-latitude oscillations of the earth's crust, the making of the earth was finally completed.

Life. — In Cenozoic time, as in the preceding æons, species were disappearing and others took their places. The Mammals of the early Eocene are different in species from those of the later; and these from the Miocene, the Miocene from the Pliocene, and the Pliocene from the Quaternary.

According to the present state of discovery, Mammals commenced in Mesozoic time, late in the Triassic era, and the Mesozoic species were probably all Monotremes and Marsupials. They were the precursor species, prophetic of that expansion of the new type which was to take place after the Age of Reptiles had closed. In the early Eocene, at the opening of the Age of Mammals, appeared Ungulates and Creodonts of large size. The earliest Ungulates (such as *Phenacodus*, Fig. 443, page 395) were scarcely distinguishable from the earliest representatives of the Carnivores (Creodonts); but more typical representatives of both groups appeared before the close of the Eocene. In the early Tertiary there were Perissodactyls allied to the Tapir and Rhinoceros, and Artiodactyls allied to the Hog. Proboscideans commenced in the Miocene, though the Elephant proper appeared first in the Pliocene. Deer and Antelopes commenced in the Miocene, Oxen in the Pliocene.

GENERAL OBSERVATIONS ON GEOLOGICAL HISTORY.

LENGTH OF GEOLOGICAL TIME.

By employing as data the relative thickness of the formations of the geological ages, estimates have been made of the time ratios of those ages, or their relative lengths (pages 317, 379). These estimated time ratios for the Paleozoic, Mesozoic, and Cenozoic, are 12 : 3 : 1. But the numbers may be much altered when the facts on which they are based are more correctly ascertained. It is quite certain that the Eopaleozoic (Cambrian and Lower Silurian) was, at the least, three times as long as either the Devonian or Carboniferous, and longer than the entire Neopaleozoic; and probable that Mesozoic time was not less than three times as long as Cenozoic.

Hence comes the striking conclusion that the longest age of the world since life began was the earliest — when the earth's population (with the exception of a few Insects and Fishes, in the latter part of the time) included only marine Invertebrates. And the time of the earth's beginnings before the introduction of life must have exceeded in length all subsequent time.

The actual lengths of these ages it is not possible to determine even approximately. All that Geology can claim to do is to prove the general proposition that Time is long. If time from the commencement of the Cambrian included 48 millions of years, which most geologists would pronounce too low an estimate, the Paleozoic part, according to the above ratio, would comprise 36 millions, the Mesozoic 9 millions, and the Cenozoic 3 millions.

One of the means of estimating the length of past time is that afforded by the rate of recession of the Falls of Niagara. The river below the Falls flows northward in a deep gorge, with high rocky walls, for seven miles, toward Lake Ontario. It is reasonably assumed that the gorge has been cut out by the river, for the river is now accomplishing work of this very kind. By certain fossiliferous Quaternary beds over the country bordering the present walls, and by other evidence, it is proved that at least about six miles of the present gorge, and probably the whole seven miles, was made after the retreat of the ice sheet of the Glacial period from that part of the country. A comparison of surveys made respectively in 1842 and 1886 shows that the recession of the apex of the Horseshoe Fall during that time has been at the rate of about four feet per year. On the basis of that determination, the time occupied in the erosion of the entire gorge has been estimated at from 6000 to 10,000 years. It is, however, believed by many geologists that, during a part of the time, the water of the Upper Lakes (Superior, Michigan, Huron) was diverted into another channel. On that supposition, the estimate of the time required for the cutting must be considerably increased—perhaps to about 30,000 years. In any case, when it is considered that the work has been done in a small fraction of the latest and shortest of the geological eras, the calculation may be regarded as establishing, at least, the proposition that Time is long, although it affords no satisfactory numbers.

Besides the estimates of geological time based on processes of erosion and sedimentation, other estimates have been made by physicists based on the conditions of cooling of the earth and the sun.

While neither the geological nor the physical modes of calculation can yield any certain results in the present state of our knowledge, it may be considered probable that geological time from the beginning of the Cambrian is measured by tens of millions, rather than by millions, or by hundreds of millions, of years.

GEOGRAPHICAL PROGRESS IN NORTH AMERICA.

The principal steps of progress in the continent of North America are here recapitulated:—

1. The continent at the close of the Archæan lay spread out mostly beneath the ocean (map, page 237). Although thus submerged, its outline was nearly the same as now. The dry land lay mostly to the north, as shown on the map. The form of the main mass approximated to that of the letter V, and the arms of the V were nearly parallel to the present coast lines.

2. Through the Paleozoic ages, as the successive periods passed, the dry land gradually extended itself southward, owing to a gradual emergence; that is, the sea border at the close of the Lower Silurian was probably as far south as the Mohawk valley in New York; at the close of the Upper Silurian it extended along not far from the north end of Cayuga Lake and Lake Erie; and by the close of the Devonian era the state was a portion of the dry land nearly to its southern boundary. This southward progress of the sea border in New York may be taken as an example of what occurred along the borders of the Archæan farther west. In other words, there was through the Cambrian, Silurian, and Devonian ages a gradual extension of the dry part of the continent southeastward and southwestward.

By the close of the Carboniferous era, or before the opening of Mesozoic time, the dry portion appears to have so far extended southwardly as to include nearly all the area east of the Mississippi, at least north of the Gulf States, along with a part of that west of the Mississippi, as far as the middle of Kansas.

3. During the Paleozoic ages, rock formations were in progress over large parts of the submerged portions of the continent; and some vast accumulations of sand were made as drifts or dunes over the flat shores and reefs. These rock formations had in general ten times the thickness along the Appalachian region which they had over the interior of the continent; and they were mostly fragmental deposits in the former region, while mostly limestones in the latter. Hence two important conclusions follow: —

First. The Appalachian region was through much of the time a sea-border region, receiving the debris from the land. There was a strip of emerged land along the Appalachian region at the close of Archæan time, and Cambrian and Lower Silurian deposits were formed on both sides of the emerged land. At the close of the Lower Silurian, a considerable region emerged, adjoining the Archæan area on the east. Along the western shore of this broad area of dry land, the debris accumulated to form the later Paleozoic deposits. At the same time the Interior region was a mediterranean sea, whose pure waters over large areas, mostly free from mechanical sediments, afforded the conditions for a luxuriant growth of the marine life whose skeletons are the material for the making of limestone.

Secondly. The Appalachian region was undergoing great changes of level, the deposits having been made in shallow waters; the region was slowly sinking, not faster than the rate of deposition, and the amount of subsidence exceeded by ten times that in the Interior Continental region.

4. In this Appalachian region, the Taconic range (and probably a system of contemporaneous ranges farther south) was upturned, rendered metamorphic, and elevated above the ocean's level, at the close of the Lower Silurian; and at the same time the valley of Lake Champlain and Hudson River was formed, if not earlier begun. At the same time, also, the Atlantic Border region south of New York emerged by an extensive geanticlinal movement, forming a land mass of unknown breadth, whose denudation in later Paleozoic time furnished material for the thick sediments of the Appalachian range proper.

5. As Paleozoic time closed, an epoch of revolution occurred, in which the rocks of the Appalachian region south of New York and west of the Piedmont region of ancient crystalline rocks underwent (1) extensive flexures or foldings; (2) immense faultings in some parts;

(3) consolidation, and, in some eastern portions, some degree of metamorphism, with the conversion of bituminous coal into anthracite. These changes affected the region from New York to Alabama. The effects of heat and uplift were more decided toward the Atlantic than toward the Interior, showing that the force producing the great results was exerted in a direction from the Atlantic, or from the southeast toward the northwest. The Appalachian Mountains proper were then made; and they were, consequently, in existence when the Mesozoic era opened.

These mountains are parallel to the eastern outline of the original Archæan continent.

Some disturbances probably took place at the same time in the Great Basin; but no general revolution on the Pacific side comparable to that on the Atlantic.

In Europe, also, this epoch of revolution was a time of mountain-making.

6. In early Mesozoic time (the continent being largely dry land, as stated in the latter part of § 2), long depressions in the surface of the continent, made in the course of the Appalachian revolution, and situated between the Appalachians and the sea border, were brackish-water estuaries, or were occupied by fresh-water marshes and streams; and Mesozoic sandstones, shales, and coal beds were formed in them. The Connecticut Valley region of Mesozoic rocks (page 332) is one example. At the same time there were formations in progress over the Rocky Mountain region, a vast area from which the sea was not excluded, or only in part. At the close of the Jurassic period, the Sierra Nevada and some other great ranges on the western side of the continent were made.

7. In the later Mesozoic, or the Cretaceous era, the Atlantic and Gulf Borders of the continent were under water (the Atlantic geanticline formed at the close of the Lower Silurian having become submerged), and received a deposit of Cretaceous rocks. The Western Interior

sea, opening south into the Gulf of Mexico, still existed, and was probably for the most part a deeper and clearer sea than in the earlier Mesozoic. Deposits were made in it over a very large part of the great region reaching from Iowa on the east to the Colorado on the west, and northward probably to the Arctic Ocean. The Pacific Border was also receiving an extension like the Atlantic.

8. Mesozoic, like Paleozoic, time closed with a revolutionary epoch of mountain-making; but the theater of this Laramide, or post-Mesozoic, revolution was on the western side of the continent. The elevation extended along the whole line of the summit region of the Rocky Mountains from near the Arctic Ocean to central Mexico; and in all probability the long line of the Andes shared in the movement. The Rocky Mountain and Sierra ranges are parallel to the western arm of the Archæan V, as the Taconic and Appalachian ranges are parallel to its eastern arm.

9. In the early Cenozoic, or the Tertiary era, the extension of the Atlantic and Pacific Borders was still continued. With its close the progress of the continent in rock-making southeastward and southwestward was very nearly completed.

The Interior sea, after the Laramide revolution, became dry land, except remnants left as great fresh-water lakes, a transition from marine to terrestrial conditions being shown by the coal-bearing strata of the Laramie epoch. During the Eocene Tertiary, the Ohio and Mississippi emptied into a bay of the Gulf of Mexico, just where they now join their waters; at the close of the Eocene the Ohio had taken a secondary place as a tributary of the Mississippi. The great Missouri River, now the main trunk of the Interior river system, began its existence after the Cretaceous period, and reached its full size only toward the close of the Tertiary, when the Rocky Mountains finally attained their full height.

10. The continent being thus far completed, as the Qua-

ternary Age was drawing on, operations changed from those causing southern extension, to those producing movements of ice and fresh waters over the land, especially in the higher latitudes; and thereby the surface of the continent acquired its present character.

PROGRESS OF LIFE.

In the summary of the characteristics of the successive æons and eras of geological time given on page 233, the student's attention was called to two generalizations: first, that in the progress of time there has been an increasing approximation to the flora and fauna of the present age; second, that there has been a rise in the grade of plants and animals represented. It was then remarked that these generalizations were strikingly in accord with the theory of evolution, now almost universally adopted. The student is now prepared to take a fuller survey of the general laws of progress in the history of life, and to recognize the significance of those laws in relation to evolution.

It would be inappropriate in this place to discuss the evidences of evolution outside of the sphere of geology and paleontology — those, for instance, which are afforded by the homologies of structure maintained in spite of wide diversity of function, by rudimentary organs, by the laws of embryology, by the facts of geographical distribution, and by the difficulties and uncertainties of zoölogical and botanical classification. Only the bearings of the geological history of plants and animals can be here presented.

The concurrence of evidence from many different sources has brought about a substantially unanimous opinion among naturalists, that the existing species of plants and animals have originated by descent with modification, from species that preceded them in geological time, and these, in turn, from still earlier species, and so on to the simplest living forms with which life is supposed to have commenced. There is, however, much uncertainty and much difference of opinion in regard to the method of evolution and the forces which have operated in the production of the result. It is generally believed that the changes from generation to generation, which have resulted in the evolution of new species, are mainly due, directly or indirectly, to the influence of environment. Some naturalists attribute very much to the direct influence of environment, assuming that the effects of use or disuse of organs, and other effects produced in the lifetime of individuals by the environment, will be inherited in greater or less degree by their offspring, and may, therefore, be accumulated from generation to generation. Others believe that comparatively little is due to the direct influence of environment. All agree that a most potent influence in evolution is the indirect influence of environment, as formulated in Darwin's principle of *natural selection.* According to this principle, those individuals in each generation whose peculiarities of organization are most thoroughly adapted to the environment will have the greatest chance of surviving to maturity and leaving offspring. In this manner, whatever may be the causes of variation, all variations which place the individual more in harmony with its environment will tend to be preserved and accumulated from generation to generation. Some naturalists have imagined innate tendencies to progress in the organization of species, and other occult or transcendental forces tending to evolution. There may be causes of evolutionary change as yet entirely unknown. In so far as evolution depends, either directly or indirectly, upon the influence of environment, it is obvious that evolutionary changes in flora and fauna must have gone on rapidly only when rapid changes have taken place in the environment. The geological record seems to indicate that, in every region of the globe, there have been long periods of comparative stability in geographical conditions, alternating with epochs of comparatively rapid change. Evolution cannot, therefore, have progressed at uniform rate through geological time, but periods of comparatively rapid evolution must have alternated with long ages of approximately stationary conditions. It is uncertain to what extent the evolution of new species has taken place by the accumulation of minute variations from generation to generation, and to what extent occasional abrupt variations have contributed to that result. On the latter supposition, it is obvious that the series of intermediate forms, which must have existed between an ancestral species and a species derived from it, would have shown much less fine gradations than on the former.

The General Fact of Progress in Life. — In the survey of geological history which the student has now completed, he will have been impressed continually with the general fact of progress. In the Cambrian, the only plants were Seaweeds. Acrogens made their first appearance in the Lower Silurian, and became abundant in the Devonian and Carboniferous. Gymnosperms first appeared in the Devonian, and culminated in the Mesozoic. Angiosperms began in the Cretaceous, and attain their greatest development at the present time. The Echinoderms of the Cambrian were Crinoids, the lowest class of the subkingdom. The Echinoids, the highest of the classes possessed of well-developed skeletons, in that subkingdom, appeared as early as the Lower Silurian; but the highest group of this class; the Irregular Echinoids, did not appear till the Jurassic. The class of Gastropods commenced, indeed, in the Cambrian, but the higher families of that class, characterized by the most specialized types of dentition, did not appear until the Mesozoic. Of the Cephalopods, the lower order, the Tetrabranchs, appeared in the Cambrian, but the higher order, the Dibranchs, not till the Triassic. The most of the Crustaceans of early time belonged to the lower subclass, the Entomostracans. The higher subclass of Malacostracans was, indeed, represented in the Cambrian, but only by its lowest order, the Leptostracans, an order somewhat intermediate in character between the two subclasses. The higher orders of Crustaceans appeared much later. The Macrurans made their first appearance in the Devonian, and Brachyurans not till the Jurassic. With the exception of some Neuropters and possibly a few Beetles, the Hexapod Insects in the Paleozoic all belonged to the orders with incomplete metamorphosis. The higher orders of Insects, exhibiting distinctly in their development the three stages of larva, pupa, and imago (complete metamorphosis), belong to Mesozoic and Cenozoic time. The highest of the subkingdoms, the Vertebrates, did not appear at all in the Cambrian. Fishes first appeared in the Lower Silurian, Amphibians in the Devonian, Reptiles in the Permian, Birds and Mammals not till the Mesozoic. The Reptiles of the Permian belonged mostly to the comparatively low order of Rhynchocephala. The more highly organized Dinosaurs and Pterosaurs did not come in till Mesozoic time. The Birds of the Jurassic, and some of those of the Cretaceous, still retained characteristics allying them to Reptiles. The Mammals of the Triassic were probably all Monotremes, and those of the Jurassic and the Cretaceous probably all Monotremes and Marsupials. The higher subclass of Placentals probably made its first appearance in the Eocene, and Man himself marks the culmination of living nature in the Quaternary.

Cephalization. — The progress of animal life in general, and the progress within each group of the animal kingdom, involves a manifestation in increasing intensity of the fore-and-aft structure, which has been stated (page 58) to be characteristic of animal life. Bilateral symmetry takes the place of radial symmetry, as shown by the contrast between the Regular Echinoids, which appeared even in the Paleozoic, and the Irregular Echinoids, which were unknown till the Jurassic. The posterior portion of the body tends to become abbreviated, and power and function to be concentrated in the organs and appendages of the anterior portion of the body, as is seen in comparing the Macrurans, which appeared in the Devonian, with the Brachyurans, which first appeared in the Jurassic. The cephalic nerve mass, or brain, acquires increasing size with the increasing activity and intelligence of the animal. See, for illustration, the figures of casts of Mammals' brains on page 397.

Parallelism of Paleontology and Embryology. — Agassiz long ago called attention to the fact that, in their development, many animals pass through embryonic or larval forms more or less closely resembling animals of lower grade, which appeared in earlier geological periods. The Crabs, through all of their earlier stages of development, have a long tail-like abdomen, such as is permanent in the Shrimps and other Macrurans. The embryo Spider has the abdomen segmented, as in the adult of the more ancient group of Scorpions. Indeed, some of the earliest Spiders, in the Carboniferous period, show traces of this segmentation in the adult. The modern Ganoids and Teleosts pass through an embryonic stage, in which they have heterocercal tails like the Ganoids of the Paleozoic. The embryos of Reptiles, Birds, and Mammals have on each side of the neck a row of gill slits like those of Sharks.

Progress from Generalized to Specialized Forms. — It was remarked on page 396 that the representatives respectively of the Ungulates and the Carnivores in the earliest Eocene are scarcely distinguishable from each other; whereas, in the progress of time, the divergent evolution has led to a stronger accentuation of the characters of the respective groups, as is seen when we contrast the limbs or the dentition of the Horse and the Cat. This case of the Tertiary Mammals well illustrates a general law. As we go back in geological time, the lines of descent appear to converge, indicating that forms now widely separated may have been derived by divergent modification from a common ancestry. The Ganoids, whose scales are preserved in Lower Silurian rocks, appear thus to have formed the starting point of two divergent lines of evolution. In *one* direction the accentuation of piscine characters resulted in the Homocercal Ganoids and Teleosts, while the other line ascended through the Dipnoans to the Amphibians and thence to the higher classes of Vertebrates. It was long ago pointed out by Agassiz that the earliest representatives of a group of animals often possessed characteristics which appeared to connect them with some other group. Such forms were called by him synthetic types. By others they have been named comprehensive types. Numerous examples of such comprehensive types occur in geological history, and it is noteworthy that they have, in general, become extinct or nearly so. The Dipnoans, blending with the characters of the Fishes the pulmonary respiration and mode of articulation of the lower jaw characteristic of the higher Vertebrates; the Labyrinthodonts, retaining fishlike structures in their skeletons; the Dinosaurs, with their birdlike limbs and pelvic girdles; the Reptilian Birds, with their teeth, and long tails, and free metacarpals; the Monotremes, with their reptilian characters in skeleton and reproductive organs; — are striking examples of such comprehensive types.

Progress in Diversification of Type. — It is a noteworthy fact that no classes (in the classification of animals adopted in this work), and very few orders, have ever become extinct, while in the progress of geological time several classes and a much larger number of orders unknown in the Cambrian have been introduced. The result has been an increasing diversification. The introduction of higher classes and orders has not involved the extinction of lower types. In some cases evolution has involved a degradation, so that relatively low forms have appeared later than allied forms of higher grade. The Ichthyosaurs, Reptiles degraded to fishlike form and habit, did not appear till the Triassic, although Reptiles of more normal structure were already in existence in the Permian. And, while the true Lizards appeared in the Jurassic, the Snakes, which are essentially Lizards that have suffered degradation in the loss of limbs, did not appear until late in the Cretaceous. So, among Mammals, although a number of the comparatively normal orders of Placentals were represented in the earliest Eocene, the Whales did not appear till later in the Eocene; and the Edentates, whose degraded character is shown in the imperfection of their teeth, did not appear till the Miocene.

Progress from Marine to Terrestrial Life. — So far as our present knowledge goes, the life of the Cambrian, both vegetable and animal, was exclusively marine. The earliest forms of life were probably creatures floating on the surface of the sea; and animals developed heavy skeletons, and took to crawling upon the bottom or attaching themselves thereto, only in a later stage of evolution (see page 251). In the Lower Silurian we get the earliest traces of terrestrial life, in Acrogens and Insects; but it is not until the Carboniferous that terrestrial life attains a very great development; and Phanerogams among plants, and Insects, Birds, and Mammals among animals, the forms of terrestrial life now dominant, belong chiefly or exclusively to Mesozoic and Cenozoic time.

Increasing Approximation to the Present Flora and Fauna. — The dominant groups of Paleozoic life are, without exception, groups which are now comparatively rare or entirely extinct. The gigantic Sigillarids, Lepidodendrids, and Calamites that characterized the Carboniferous forests, are now represented by insignificant forms which make no conspicuous feature in the vegetation. Cyathophylloid Corals have only doubtful representatives after the Paleozoic. Crinoids decrease in abundance after the Paleozoic, and the class is now but very scantily represented. The groups of Cystoids and Blastoids are exclusively Paleozoic. The class of Brachiopods, whose remains in the early Paleozoic outweigh all other fossils put together, is now reduced to an insignificant remnant. Of Tetrabranch Cephalopods, the genus *Nautilus* is now the sole survivor. The Trilobites and the *Placoderms* are unknown since the Paleozoic.

The life of the Mesozoic shows a greater resemblance to the life of modern times. The forests of Acrogens are succeeded in the early Mesozoic by forests of Gymnosperms, and in the Cretaceous Angiosperms appear. Brachiopods gradually decline, and Lamellibranchs gradually increase. The order of Tetrabranchs is represented by a vast multitude of Ammonites, but associated with them are Belemnites and other representatives of the Dibranchs. Insects appear in increasing numbers, and most of the higher orders are represented. Reptiles attain their culmination; and, before the close of the Mesozoic, the modern groups of Teleost Fishes, Birds, and Mammals appear.

The Cambrian fauna includes not a single *species* now surviving, and only two *genera* represented by living species, *Lingula* and *Discina*. It is doubtful even whether the Cambrian Brachiopods referred to those two genera really belong to them. Before the close of the Paleozoic, a considerable number of genera appear which are still represented by living species; but no Paleozoic species, either of plant or animal, has survived to the present time, with the doubtful exception of a few species of Carboniferous Diatoms. It is doubtful whether any Mesozoic species of animal, except a few species of Foraminifers, has survived to the present day, although the number of genera represented by living species becomes considerable. With the beginning of the Tertiary, existing species of Invertebrates make their appearance; and, by the close of the Tertiary, the Plants and Invertebrates are mainly of species which still survive. During the Quaternary, existing species of Vertebrates are gradually introduced.

Gradual Change in Genera and Species. — As we pass from one stratum to another within the limits of a formation, it may generally be observed that some species disappear, and others take their place. At the close of an epoch or a period, a greater proportion of the life is changed. The diagram on page 322, showing the range of some of the principal genera of Trilobites, illustrates well the history of most groups of organisms. Each class or order generally appears first in comparatively small numbers of species, and increases to a culmination, after which it may gradually decline; and during the lifetime of a class or order there is a constant appearance and disappearance of genera and species. It is not certain that any species represented in the Paleozoic appears in the Mesozoic, and scarcely any Mesozoic species appear in the Cenozoic; but, at the present day, all geologists would explain this condition, not by the supposition of universal exterminations, but by reference to the imperfection of the geological record (page 461).

The cause of the extinction of species must be supposed to be, in general, an unfavorable environment. When the environment changes so that a species is no longer in harmony with it, the species may undergo modification, if the change of environment is not too rapid, or may migrate, if areas are open to it in which the environment is more favorable. Otherwise it must become extinct. Changes of climate have probably been, on a large scale, the most important influence in determining such evolutionary changes. The amount of heat received from the sun has appreciably declined through geological time. The water vapor, with which the atmosphere of earlier ages was loaded, has been gradually condensed; and the carbon dioxide has been gradually removed from the atmosphere, and its carbon stored in various forms in the crust of the globe. The earth's atmosphere has thereby become less absorptive of heat, and opposes less resistance to the radiation of heat from the earth. Oscillations of level of the earth's crust have directly affected the temperature of the areas of elevation or subsidence, and have indirectly affected the temperature of other regions by changing the courses of ocean currents. While changes of climate have often operated simultaneously over a large part or the whole of the surface of the globe, every movement of elevation or subsidence, however slight, has made local changes in the conditions of life. Land has been converted into sea, and sea into land; salt water has given place to fresh, and *vice versa;* muddy shoals, receiving detritus from the shore, have given place to clear seas in whose pure waters corals could grow luxuriantly; and, again, the debris of the coral gardens has been covered with mud or gravel. Exterminations of more local character have been produced by various catastrophes, as earthquake waves deluging the areas of land, volcanic eruptions heating the waters, or emanations of gas rendering the waters poisonous. And the conditions of life of every species have been affected not only by the direct influence of geographical or climatic changes, but indirectly by the changes in the forms of life with which it has been associated. Migration brings a species into relation with a different set of other species, which may furnish it with food, or become its rivals or enemies.

Lost Groups do not reappear. — As a general rule, a species, or a more comprehensive group, which has once become extinct, does not reappear. To this proposition there are some curious apparent exceptions. A few land Snails are found in the Carboniferous, but no land Snails have been recognized from the Permian, Triassic, or Jurassic formations. In the Cretaceous they reappear, and from that time the series is substantially continuous. A few Scorpions are found in the Upper Silurian; none have been recognized from the Devonian; but in the Carboniferous both Scorpions and Spiders occur. Both these groups appear to be missing from the Permian and from the whole series of Mesozoic strata. They reappear in the Tertiary. Amphibians of the order Labyrinthodonts appear in the Subcarboniferous (or, probably, in the Devonian), and continue through the Triassic, possibly into the beginning of the Jurassic. The class of Amphibians then remains unrepresented until a Salamander appears in the Lower Cretaceous. Such exceptions, however, are readily explained as due to the imperfection of the record. They are not sufficient to throw any doubt upon the general principle.

Persistence of Character of Faunas. — In the early periods of the earth's history there appears to have been little differentiation between the faunas and floras of various continents. After the development of such differentiation, and the acquisition of distinct faunal characteristics by the various continents, there is a noteworthy tendency for these characteristics to persist from one geological period to another. That principle is strikingly illustrated in the comparison of the Mammalian faunas of the Quaternary with the existing faunas. In the early Quaternary, Australia was distinctively the land of Marsupials, and, in somewhat less striking degree, South America was the land of Edentates. The present Mammalian faunas of those regions are characterized by the predominance of the same types.

Missing Links. — The general laws of succession of organic life, as above formulated, are all obviously in accord with the theory of evolution. Yet there are paleontological facts whose bearing appears, *prima facie*, adverse to that doctrine. According to the theory of evolution, existing species ought, in most cases, to be well defined, since, in general, a species now existing must be supposed to have been derived, not from some other existing species, but from a species now extinct. Between the ancestral and the derived species there must have been sometime a series of more or less finely gradational forms. How fine those gradations must have been, depends somewhat upon the method of evolution. If evolution was by the accumulation of minute and imperceptible variations, the series must have presented very fine gradations. If, as is probable, occasional abrupt variations have played a considerable rôle, the gradations would have been less fine. On that supposition, the missing links may be missing because they never existed. Certain it is that in most cases fine gradations between fossil species are no more to be found than between living species. In the great majority of cases, fossil species are well defined. Moreover, more comprehensive groups often appear in geological history where no preëxistent forms are known as probable ancestors for them; and the order of introduction of related groups is often different from that which would be predicted, *a priori*, on the basis of the theory of evolution. The highly diversified fauna of the Cambrian includes many groups of by no means very low grade, which appear without any apparent ancestry. Hexapod Insects appear in the Lower Silurian, while the Myriopods, which are more generalized, and would seem to be a more primitive group, are unknown until the Devonian. No fossil forms have been discovered which can be imagined to be the immediate ancestors of the Placoderms, Selachians, and Ganoids of the Lower Silurian. No intermediate forms have been discovered bridging the gap between Seaweeds and Acrogens. The sudden appearance of numerous orders of Placental Mammals in the very earliest Eocene is at least startling. The interrupted chronological range of several groups, as in the cases of Snails, Arachnoids, and Amphibians, above mentioned, would be a fatal objection to the theory of evolution, if the interruptions were believed to be other than merely apparent. So long as the complete change in the life of the globe at the close of the Paleozoic, and again at the close of the Mesozoic, was believed to be due to universal extermination, the theory of evolution could have no standing ground.

The Imperfection of the Geological Record. — This phrase, now become classical, expresses the substance of the answer given by Darwin, and by all evolutionists, to such difficulties as have just been cited. The bearing of the principle on some special cases has already been discussed (pages 251, 288, 289). But the subject of the imperfection of the geological record may well receive some further comment.

1. *Geological Conditions of Imperfection of the Record.*—Fossiliferous strata of considerable thickness can be formed only during a progressive subsidence; but, in general, relative elevation must have predominated over subsidence in the history of the continents; and, moreover, Darwin is probably correct in maintaining that periods of elevation have been more fruitful in evolutionary changes than periods of subsidence. After fossiliferous strata have been formed, their record has often been obliterated by metamorphism. Fossiliferous strata not of great thickness may often be entirely removed by erosion. The vast areas occupied by plutonic and metamorphic rocks afford striking proof of the enormous denudation which has taken place, since these rocks must have assumed their present crystalline character under the pressure of hundreds or thousands of feet of superincumbent rock. In no region of the globe have we any continuous series of fossiliferous strata, and in many districts only mere fragments of the series are present. The most abrupt changes in the fossil contents of strata usually occur where the strata are unconformable; and unconformability, as explained on page 57, is always the sign of a lost interval in the record. It must, moreover, be considered that the period whose record is lost by unconformability is necessarily a period of geographical change for the region in question. The area which had been receiving sediment has been elevated so as to become dry land, and, after a longer or shorter period of erosion, has been again depressed below the water level. These times of geographical, and consequently of climatic, change, are the times in which evolutionary changes in the fauna and flora are necessarily most rapid. The geological record is therefore defective by the loss of those chapters which, if present, would afford the history of the most critical periods. The great changes in fauna and flora at the close of the Paleozoic and the Mesozoic are thus naturally correlated with the great geographical revolutions which occurred at those times.

2. *Biological Conditions of Imperfection of the Record.* — The vast majority of living beings die under such circumstances that there is no chance of their fossilization. In order that we may have a fossil for study, it is necessary that the entire organism, or some recognizable part of it, should be buried, before it can be decomposed or dissolved (or at least an impression of the organism made), in some deposit which is subsequently preserved without too much alteration, and brought into an accessible position. Only under an exceptional combination of circumstances can this be the fate of an individual plant or animal. The chance of such preservation is greater in the case of aquatic, than in that of terrestrial, animals and plants. It would naturally be expected, therefore, that the record of terrestrial life would be extremely ragged. Moreover, in general, only somewhat indurated structures, or skeletons, can be expected to be preserved. Terrestrial plants whose tissues contain no woody fiber, and animals that are destitute of skeleton, have but an infinitesimal chance of leaving any record. This latter principle probably affords the chief explanation of the mystery of the Cambrian fauna (page 251), although it must also be remembered that the Archæan rocks have suffered so extensive metamorphism that whatever fossils they may have contained are likely to have been obliterated, and that the universal unconformability between the Archæan and the Cambrian shows a lost interval in the record during which evolutionary changes may have been in progress.

That the geological record is extremely imperfect, is illustrated by the well-known fact that multitudes of fossil species are known as yet only by a single specimen. In many cases a family, an order, or a class, in some particular formation, may be represented by only one or two specimens. In the Jurassic formation of Europe, the class of Birds is represented by two somewhat imperfect skeletons and a single odd feather. In the Jurassic of North America, the same class is represented by a single doubtful fragment of a skull (page 345). In the Triassic of North America, the class of Mammals is represented by two lower jaws. There can be no reasonable doubt that the imperfection of the geological record affords a sufficient answer to all arguments against evolution based upon the gaps that exist in the series of fossils. Negative evidence in paleontology must be considered of very little value.

CONCLUSION.

In spite of all difficulties and uncertainties, geology is able thus to give in outline the history of the evolution of Man himself and of his dwelling place. It shows how the featureless simplicity of the molten globe has given place to continent and ocean, mountain and valley, plain and plateau, river and lake, cataract and glacier; how ores have been stored in veins, and coal accumulated in strata, and rock material crystallized into granite strength and gemlike beauty. It shows how the earth has come to be a fit dwelling place for a creature of such physical and spiritual needs and capacities as those of Man; and how, in the progress of life, those plants and animals have been evolved which could minister to Man's physical or mental life. It shows how the upward progress, from Protozoan simplicity, through Fish and Amphibian and Reptile and Mammal, has culminated at last in Man himself, the crown of creation, sharing with the animal kingdom a place in nature, but asserting by his intellectual and spiritual endowments a place above nature. While it is the work of science to trace the method of this twofold evolution, science, as such, knows nothing of efficient cause or of purpose; but it leaves full scope for faith that the Power, whose modes of working science may in part reveal, is intelligent and personal, and that the whole process of the evolution of Man and his dwelling place has been guided by infinite Wisdom to the fulfillment of a purpose of infinite Love.

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NOTE. — The asterisk after the number of a page indicates that the subject referred to is illustrated by a figure.

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